ERDC/CHL TR-12-14

Coastal and Hydraulics Laboratory

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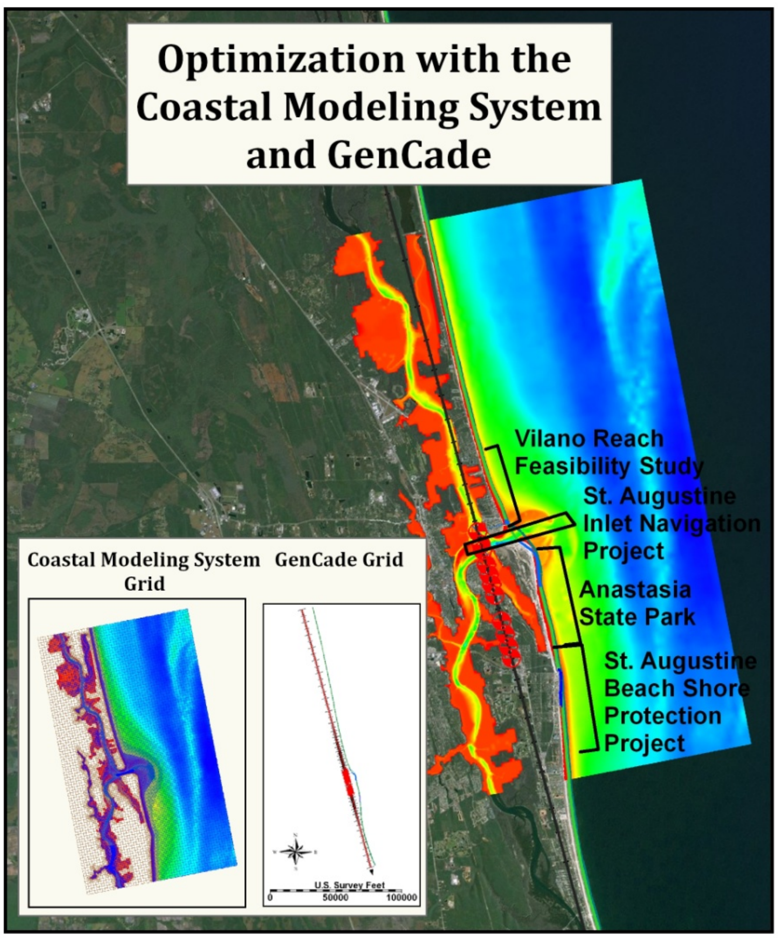
Coastal Inlets Research Program

Optimization of Ebb Shoal Mining and Beach Nourishment at St. Johns County, St. Augustine Inlet, Florida

Report 3

Tanya M. Beck and Kelly Legault

August 2012



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Report 3 of a series

Prepared for U.S. Army Engineer District, Jacksonville
701 San Marco Blvd,
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Under Coastal Inlets Research Program

Monitored by Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
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Abstract

This report, the third in a series documenting a study of St. Johns County, Florida, describes the application of GenCade to the study area as part of a greater Regional Sediment Management (RSM) study. This study illustrates the use of GenCade, a coastal evolution and sediment transport model, as a tool for optimization in management practices for Operations & Maintenance (O&M). Results of the calibration showed good agreement (NRMSE 6.8 percent, Correlation Coefficient 0.61, and Pattern Correlation 93.9 percent) with the measured sediment budget for the study area. The application of the model to calculate long-term with project sediment budget alternatives proved useful in determining an optimized schedule for sediment management activities. The ideal dredging interval for the navigation channel entrance and ebb-tidal delta mining was determined to be most beneficial at 10-year intervals, with beach fill projects being fulfilled at the most favorable placement location and highest yield volume density. The results of a 10-year incremental, strategic placement of three million cubic yards over a 50-year period will potentially save up to $10 million in mobilization costs and reduce O&M needs for the St. Johns County Federal Projects.

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Preface

This report is the third report in a series documenting a study of St. Johns County, Florida, and was performed by the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) at the request of the U.S. Army Engineer District, Jacksonville (hereafter, the Jacksonville District), as part of a greater Regional Sediment Management (RSM) study. This report describes the application of GenCade, a shoreline change and sediment transport model, and illustrates a methodology for use of the model as a tool for optimization in sediment management practices for Operations & Maintenance (O&M). The analysis conducted in this study benefitted from Technical Report 1, ERDC/CHL-TR-12-14, which developed a sediment budget based on adjacent beach profile evolution from 1999 to 2010 and attempts to answer questions posed by local authorities that address the impact of operations on the federal navigation channel at St. Augustine Inlet. Technical Report 2, ERDC/CHL-TR-12-14 analyzed the influence of ebb-tidal delta mining of the St. Augustine Inlet on the inlet morphology and sediment transport pathways. The objective of this report is to determine the near field and far field effects on sediment transport processes given past and future dredging operations at the inlet ebb-tidal delta.

The study effort was conducted during fiscal year 2011 by staff of the Coastal Inlets Research Program (CIRP), a navigation research and development program of Headquarters, USACE. The CIRP's GenCade model was applied here to quantitatively define the latitude in sediment management for St. Johns County through modeling alternative future sediment budget scenarios. GenCade is a coastal evolution model with the capacity to calculate alongshore transport of sediment over the beach and inlets and is ideal for estimating a calculated sediment budget based on historical data. The modeling system was calibrated by reproducing observed sediment transport rates, volumetric change, and inlet reservoir volumes over the study area for the time period of 1986 to 1999. The model was then applied to evaluate sediment management alternatives that applied known historical limits of dredging and beach fill quantities and intervals.

This study was performed by Tanya M. Beck, Coastal Engineering Branch (CEB), Navigation Division (ND), CHL, and Dr. Kelly Legault, Water

Resources Engineering Branch (WREB), Jacksonville District. Dr. Julie Dean Rosati, Flood and Coastal Division, Coastal Processes Branch (CPB), CHL, and CIRP Program Manager, Dr. David King (CPB), CHL, and Drs. Magnus Larson and Hans Hanson, Lund University, reviewed a draft of this document. Information and coordination in support of this study, as well as study review, were provided by Jason Engle of the Jacksonville District. This study was supported by the CIRP and the Regional Sediment Management (RSM) Program, funded by the U.S. Army Corps of Engineers, Headquarters (HQUSACE). Linda Lillycrop (CEB), CHL, is Program Manager of the RSM Program. The CIRP and RSM Programs are administered for Headquarters at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) under the Navigation Systems Program of the U.S. Army Corps of Engineers. James E. Walker is HQUSACE Navigation Business Line Manager overseeing CIRP and RSM. W. Jeff Lillycrop, CHL, is the Navigation Technical Director. This work was conducted under the general administrative supervision of Dr. Jeffrey P. Waters, Chief, CEB, and Dr. Rose M. Kress, Chief, ND.

At the time of publication of this report, COL Kevin Wilson, EN, was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was ERDC Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
yards	0.9144	meters

1 Introduction

This Technical Report is the third in a series on Regional Sediment Management (RSM) studies at St. Johns County, Florida, and uses summary information found in Technical Report 1, (Legault et al. 2012; ERDC/CHL-TR-12-14), which developed a sediment budget based on adjacent beach profile evolution from 1999 to 2010, and Technical Report 2, (Beck and Legault 2012; ERDC/CHL-TR-12-14), which analyzed the effects of ebb-tidal delta mining of the St. Augustine Inlet. These studies attempt to answer questions posed by local authorities that address the impact of federal navigation dredging operations, including ebb-tidal delta mining, on the inlet morphology and sediment transport pathways at St. Augustine Inlet, and on the adjacent St. Johns County beaches.

The primary goal of this study was to determine an optimal sediment management plan for the major, managed sediment sources and sinks in St. Johns County, specifically, the sediment reservoirs of the St. Augustine Inlet Navigation Project and the adjacent Shore Protection Projects at St. Augustine Beach and Vilano Beach (Figure 1). An optimization of these three projects is determined, first, through identifying the sustainable maximum dredging volume from St. Augustine Inlet and associated interval, and second, by evaluating the nourishment volumes and placement reaches to avoid rehandling and minimize transportation costs. Ultimately, the dredging volumes and intervals will be coupled with the necessary placement volumes and intervals to reach a long-term, sustainable management of these two beach nourishment projects over a 50-year planning horizon. To analyze the evolution of the sediment borrow site and placement regions over long temporal scales, the regional shoreline change model, GenCade, was applied to the project. GenCade is a shoreline change model with the capacity to calculate alongshore transport of sediment over the beach and inlets and is ideal for modeling a predicted sediment budget based on historical data (Connell et al. 2007; Frey et al. 2012).

To illustrate the interaction between the inlet and adjacent beaches, several extreme situations are considered. If too large a quantity is removed from the inlet shoals and placed on the adjacent beaches, the shoals may collapse (migrate onshore and/or into the navigation channel) and in the future, the inlet would reduce bypassing to the adjacent beaches to rebuild these

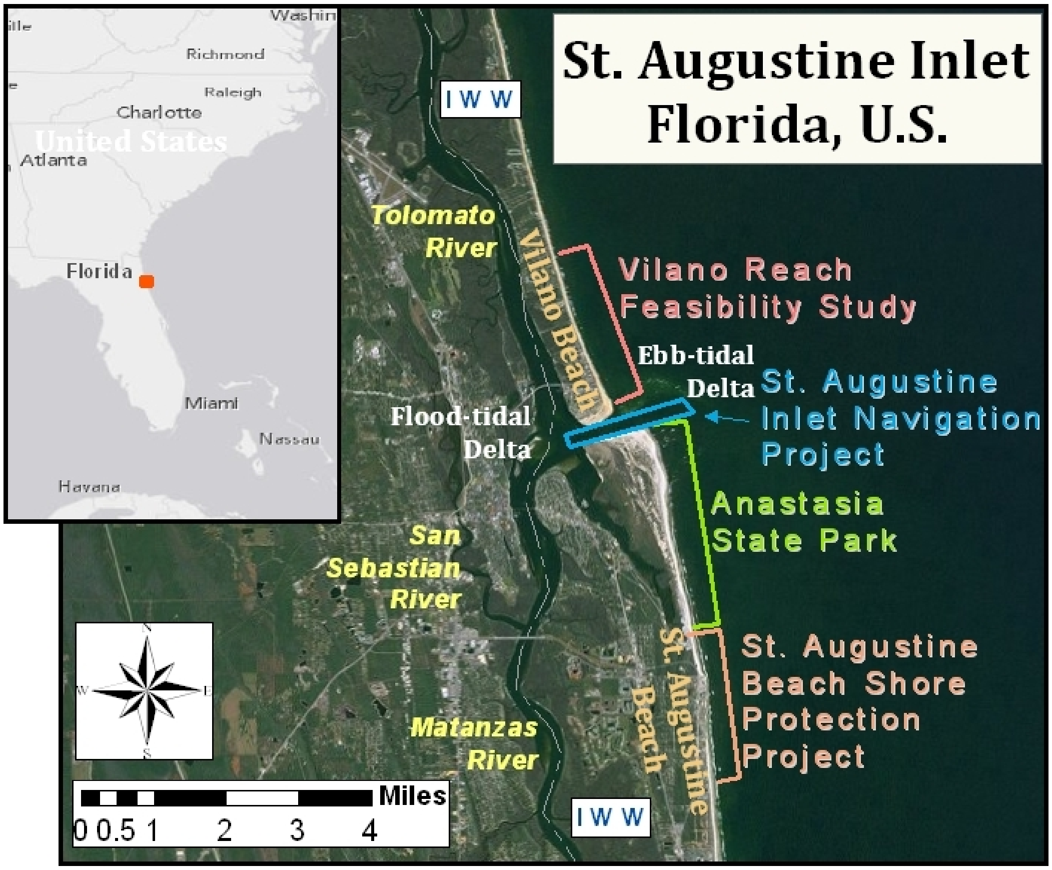

Figure 1. Study area location map for St. Johns County, Florida, and the U.S. Army Corps of Engineers' projects.: Vilano Reach Feasibility Study, St. Augustine Beach shore protection Project, Intracoastal Waterway (IWW), and St. Augustine Inlet Navigation Project. The Vilano Shoal is located at the southern terminus of the Vilano Reach Feasibility Study, and the ebb-tidal delta mining is located adjacent and offshore of the Inlet Navigation Project.

shoals, thus increasing beach erosion over the long-term. If too small a quantity is removed, the benefit of mobilization/ demobilization of the dredging and placement is not fully realized for protection of the adjacent beaches. Another case would be the placement of sand on beaches at locations too close to the inlet such that the nourishment is quickly transported into the navigation channel, therefore increasing future maintenance costs. If the sand is placed too far from the inlet, the costs incurred during the placement process are unnecessarily increased. Thus, there is likely an optimal range in volume removed from the inlet shoals and ideal locations along the adjacent beaches to minimize costs and potential rehandling of dredged sand.

The regional study area for the project at St. Johns County spans a section of the northern Florida coast from Ponte Vedra Beach south to Matanzas Inlet (Figure 2). There are three active coastal projects within the county

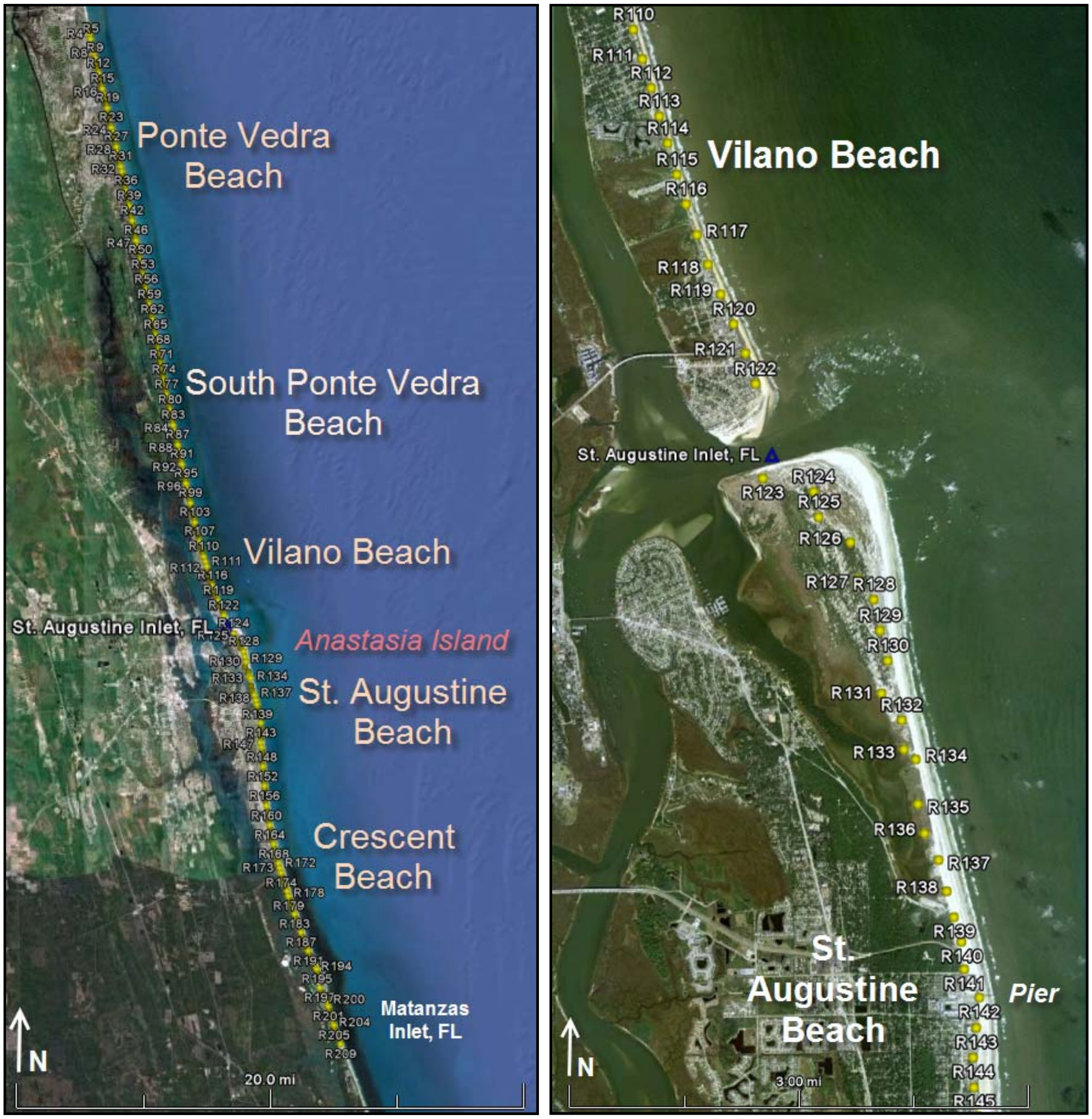

Figure 2. Study area beaches and location of FL Department of Environmental Protection designated beach profiles, R-Monuments 5 through 209 (left panel); Close up of R-Monuments near Inlet and SPP at St. Augustine (right panel).

including the St. Augustine Inlet Navigation Project, which was established in 1940 and authorized in 1941 (Taylor Engineering Inc. 1994), the Intracoastal Waterway (IWW) Navigation Project, and the St. Augustine Beach Shore Protection Project (SPP), which was authorized in 2000. Figure 1 illustrates these projects and the Vilano Reach SPP that is presently (2011-2012) in a feasibility study. The St. Augustine Inlet navigation project consists of a perpendicular cut design that is authorized to 16 ft below Mean Low Water (MLW) and an ebb-tidal delta mining area along the distal portion of the shoal. The channel is regularly maintained every 3-7 years (the IWW every 10 years), and the ebb-tidal delta mining

area has been dredged in 2001-2003 and in 2005. All sediment dredged from these areas is beach-quality sand of suitable size for use on the adjacent beaches. The St. Augustine Beach SPP is maintained through frequent, large beach fills to maintain storm protection for the region.

The Jacksonville District works with local stakeholders to cost-share the expense of mining the shoal and beach fill placement and combines this nourishment project with a navigation channel dredging operation to leverage equipment and utilize the sand. Leveraging equipment and mobilization/demobilization costs from multiple projects can save the District approximately $2 million each (personal communication with District Operations), and is therefore an optimal approach. Although the inlet navigation project provides suitable sand material that is in close proximity to the SPP, the operation likely cannot provide the quantity needed for the beach fill at St. Augustine Beach on a regular (~5 year) basis (personal communication with District Engineers). The two dredging, or ebb-delta mining, events in 2001-2003 and 2005 resulted in two major beach fill operations with each placing more than two million cubic yards of placed sand. To date (2012), recovery of the mining site has occurred at approximately the same rate as the historical measured ebb delta growth (Legault et al. 2012); however, recovery at this rate will not provide enough sediment to sustain the need for substantial beach fills at the St. Augustine Beach SPP.

With the present feasibility study at Vilano Reach underway, the Jacksonville District requested a study on the viability of coupling the Navigation and Shore Protection Projects within St. Johns County on a reoccurring interval for the next 50-year planning horizon. The issues posed are as follows:

1. How many cubic yards of sediment can be mined from the ebb-tidal delta in its present condition such that the overall equilibrium volume of the ebb-tidal delta is unaffected? In other words, what are the temporal and volumetric limits on ebb-delta mining over a 50-year planning horizon, which do not affect the overall equilibrium of the delta?
2. How much sediment is necessary to maintain a 5-year and 10-year beach fill interval for the St. Augustine Beach SPP?
3. How much more sediment is necessary to maintain a 5-year and 10-year beach fill interval for the St. Augustine Beach SPP and the proposed Vilano Beach SPP?

These questions were addressed through operation of GenCade, forced by hindcast waves, which reproduced observed trends in shoreline change. The modeling system was calibrated by reproducing observed sediment transport rates, volumetric change, and evolution of inlet sediment reservoir volumes over the study area for the time period of 1986 to 1999. The model was then applied to evaluate sediment management alternatives that applied known historical limits of dredging and beach fill quantities and intervals.

1.1 Study area

The study area for this report covers St. Johns County, Florida, which stretches 40 miles from Ponte Vedra Beach in the north to Matanzas Inlet to the south (Figure 2). The coastline in northeastern Florida has a relatively straight north-south trending shoreline, and the study area shoreline is oriented at ~165 degrees clockwise from true north. St. Augustine Inlet is centrally located within the county area. The inlet serves two rivers, the Matanzas River to the south and the Tolomato River to the north, that make up a lagoonal estuary including a tidal salt marsh system. There is little riverine flow into the estuary, and much of the estuary is brackish to marine. The rivers that comprise the lagoon are maintained as components of the IWW system.

The wave climate is seasonal with moderate wave exposure as defined by Walton and Adams (1976), and the tidal range is on the lower end of the mesotidal range (6 – 13 ft) with a spring high tidal range of 6 ft and a mean of 5 ft (NOAA 2010). Table 1 describes the general tide and wave characteristics of the area. Wave energy is typically greatest during the winter season from November to April, with subtropical frontal passages occurring on average every 3- 7 days (Taylor Engineering Inc. 1996). Waves during these storms are typically out of the north with heights on average 4- 6 ft or greater and mean wave periods of 9-12 seconds (USACE 2010). Figure 3 depicts the percent occurrence for wave height and period for the 20-year WIS hindcast period of 1980-1999. Fair-weather conditions persist through the summer season from May to October, with the exception of the occasional passage of tropical storms. Southerly waves during this season on average dominate and induce a reversal in net sediment transport direction. Overall, the net sediment transport along northeastern Florida is north to south, primarily caused by winter storms.

Table 1. General characteristics of the tide and waves in the Vicinity of St. Augustine Inlet, Florida.

General Characteristic	Value	Description
Mean Tidal Range	4.5 ft	Astronomical Tide (Taylor Engineering Inc. 1996)
Spring Mean Tidal Range	5.3 ft	Astronomical Tide (Taylor Engineering Inc. 1996)
Mean Significant Wave Height	3.6 ft	WIS Hindcast Database (USACE 2010)
Mean Peak Wave Period	7 sec	WIS Hindcast Database (USACE 2010)
Range of Mean Significant Wave Height	1.8 – 5.9 ft	WIS Hindcast Database (USACE 2010)
Range of Mean Peak Wave Period	4.8 - 10 sec	WIS Hindcast Database (USACE 2010)

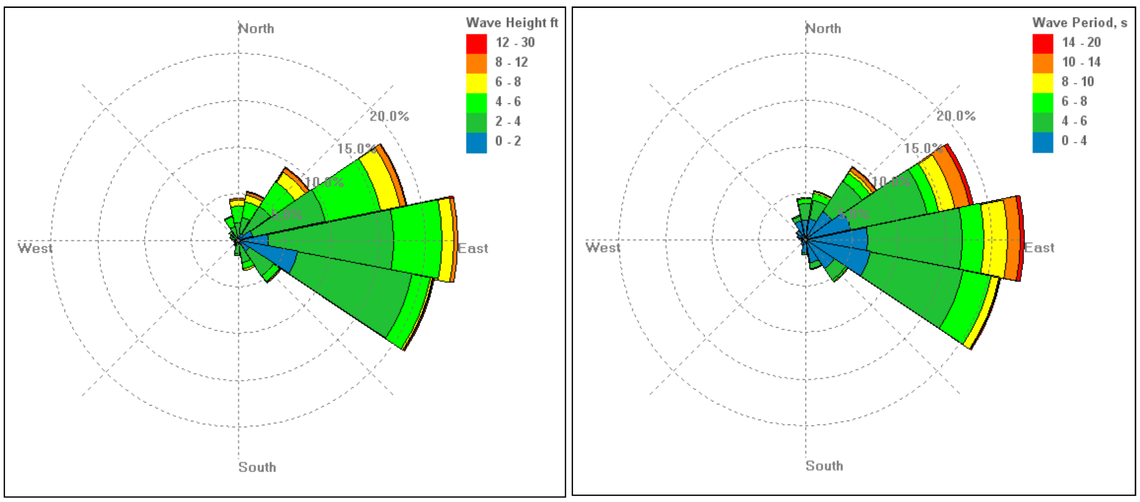

Figure 3. Wave height (left panel) and wave period (right panel) rose diagrams that give the percent occurrence of waves for the 20-year WIS hindcast for station 417.

PBS&J (2009) conducted an extensive analysis of sediments within the nearshore along northern St. Johns County. Sediments are mostly littorally derived with some bioclastic genesis (carbonate) and little to no riverine input. The sediment is primarily quartz, with significant fractions of carbonate shell hash, which sometimes dominate, and lesser amounts of feldspar. The carbonate shell hash and quartz make up the majority of sand concentration, and vary in distribution alongshore. Carbonate shell hash along the study area is greatest in concentration along South Ponte Vedra and Vilano beaches, is least across the inlet ebb-tidal delta, and is varying concentrations along the southern beaches of St. Augustine Beach and further south. Figure 4 illustrates the mean grain size distribution sampled across the beach and nearshore for eight profiles along South Ponte Vedra and Vilano beaches (PBS&J 2009). Samples were taken over intervals from +15 to -15 ft mean sea level (MSL).

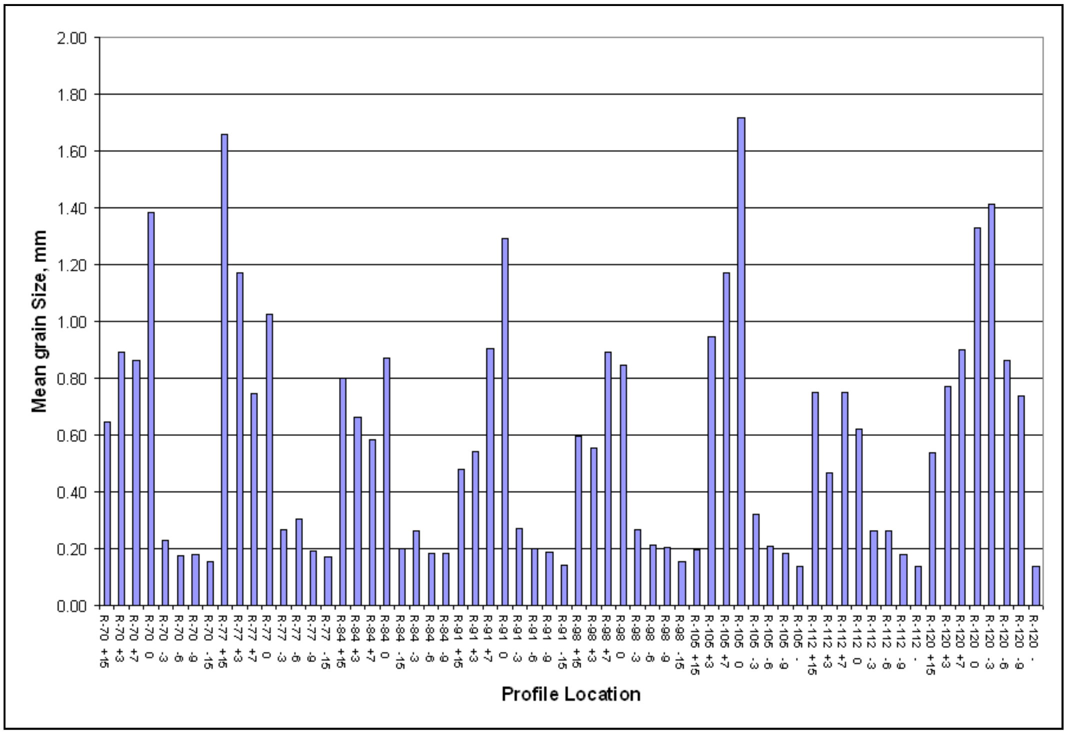

Figure 4. Mean grain size of 8 cross-shore beach and nearshore sample locations from 8 profiles along the South Ponte Vedra and Vilano beaches. Samples were taken at cross-shore locations ranging from +15 to -15 ft MSL. (Graph from PBS&J 2009.)

Regional sand transport and volumetric change observed from beach profiles collected by the Florida Department of Environmental Protection (FDEP) and the Jacksonville District are described extensively in Report 1 (Legault et al. 2012). Figure 2 shows location of these profiles for the region, which extend from R1 in the north to R209 in the south. The inlet is bracketed by R122 to the north and R123 south of the inlet throat. To summarize, Figure 5 shows average annual volume change per summed profile reach (5000 ft, or five R-Monuments) for the time period from 1986-1999, (pre-dredging) and for the time period from 1999-2007 (post-dredging). In general, for the pre-project period (1986-1999), there is erosion north of the inlet from R1-R122, with accretion immediately south of the inlet from R124-R128, then greatest erosion around R135 -R150, and milder erosion south of R150. Beach nourishment for both the 2001-2003 and 2005 projects was placed between R132-R151, although with differing distributions. For the time period from 1999-2007 that includes both ebb shoal mining and placement, illustrated by the dark grey bars in Figure 5, an observable decrease in average annual reach volume change exists from R70 to the inlet, which may be singularly attributed to the effect of the inlet (see Report 1, Legault et al. 2012). Figure 6 illustrates the directions of net transport along the coast of St. Johns County, particularly illustrating the

reversal in net transport located near the tidal inlet. The net transport on the southern beaches is toward the south, however a divergent nodal zone in transport (reversal) is estimated to be located near R132 and a strong erosional signal is present at R142, the location of St. Augustine Beach Pier (Figure 6). Over the latter time period, from 1999 to 2007, Anastasia State Park experienced significant accretion where the region directly to the south, at St. Augustine Beach Pier experienced significant erosion.

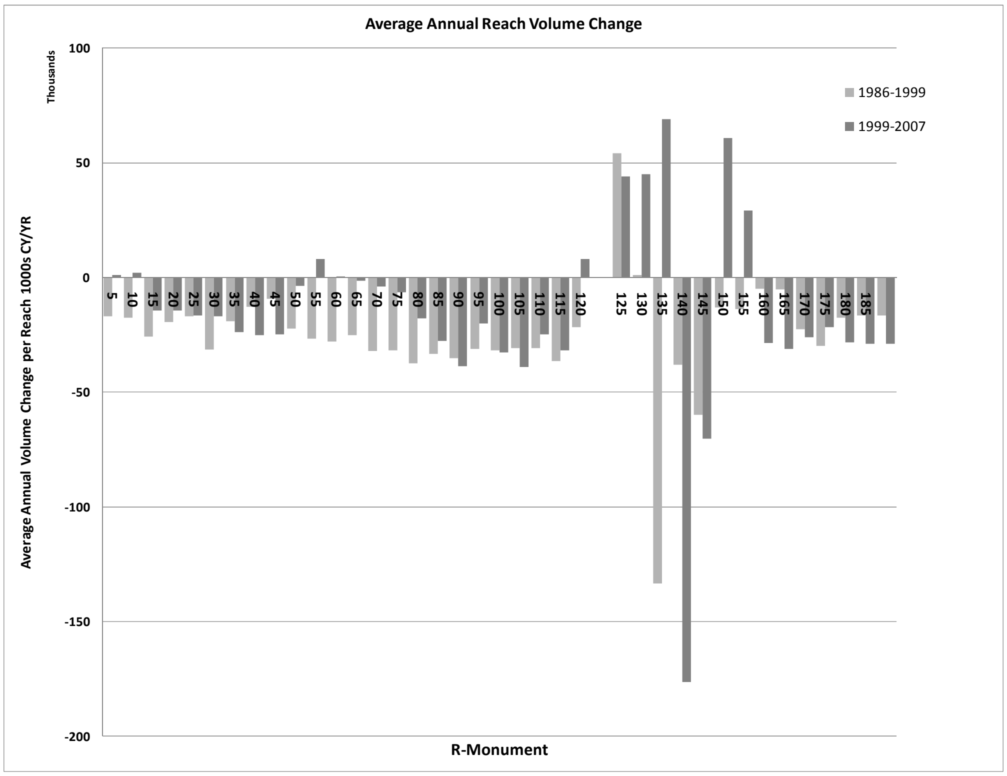

Figure 5. Average annual reach volume change 1986-1999 and 1999-2007. Reaches are approximately 5000 ft in the alongshore.

1.2 Gencade: A shoreline change model

GenCade is a one-dimensional (1-D) numerical model that calculates regional coastal change including inlet morphologic feature evolution. The model is a combination of Genesis (Hanson and Kraus 1989; Hanson 1989; Gravens et al. 1991), a shoreline change model designed for project-scale engineering studies, and Cascade, a regional alongshore sediment transport model that includes barrier islands and the inlets that separate them (Larson et al. 2003; Larson and Kraus 2003; Larson et al. 2006; Connell and Kraus 2006; and Larson et al. 2007; Connell et al. 2007). The combination of the two models into GenCade, with the addition of the Inlet Reservoir Model (Kraus 2000, 2002) which investigates the

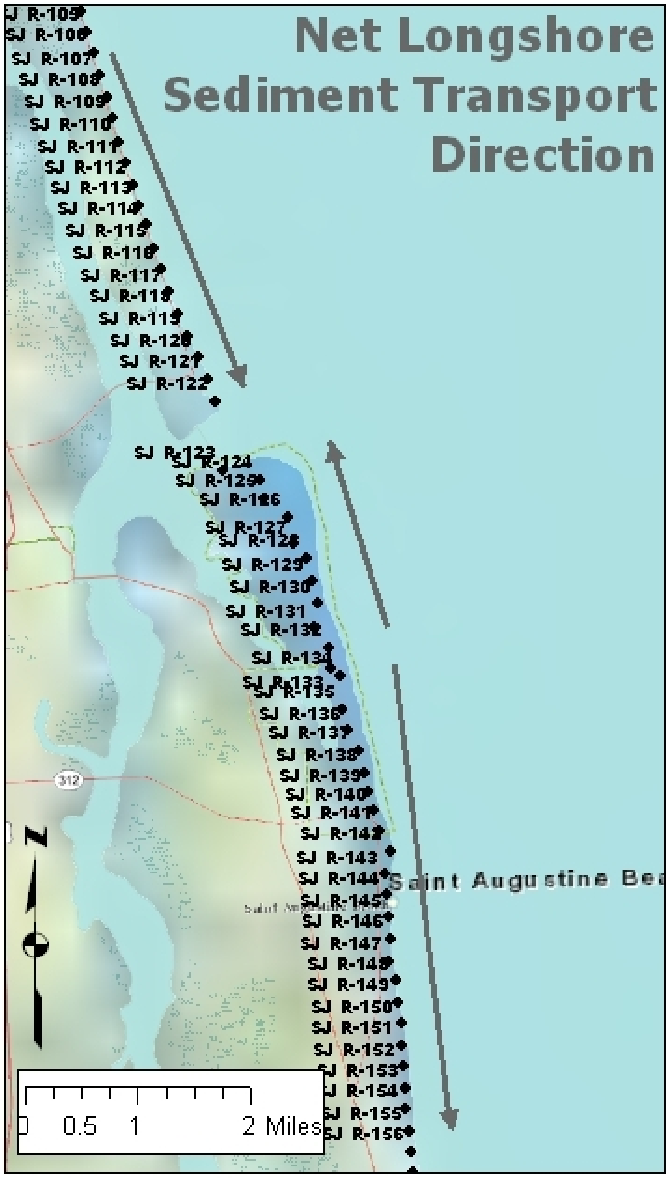

Figure 6. General net longshore sediment transport directions in the vicinity of the inlet.

sediment sinks in inlets, resulted in a regional model capable of modeling shoreline change at the structure or project level, up to regional distances on the order of hundreds of kilometers (Figure 7). Wave parameters (significant wave height, wave period, and wave direction), input into stations along the grid, are transformed to breaking depth and used as inputs to calculate longshore sediment transport rates along the 1-D GenCade grid. Sediment transport rates are calculated for each cell along the grid, including the sediment moving into and out of an inlet reservoir, and volume changes are given by the sand-volume conservation equation. Outputs from the regional model are the gross sediment transport rate, the

net sediment transport rate magnitude and direction, the shoreline change rate, and the alongshore volume change rate, providing a sediment budget for the modeled region.

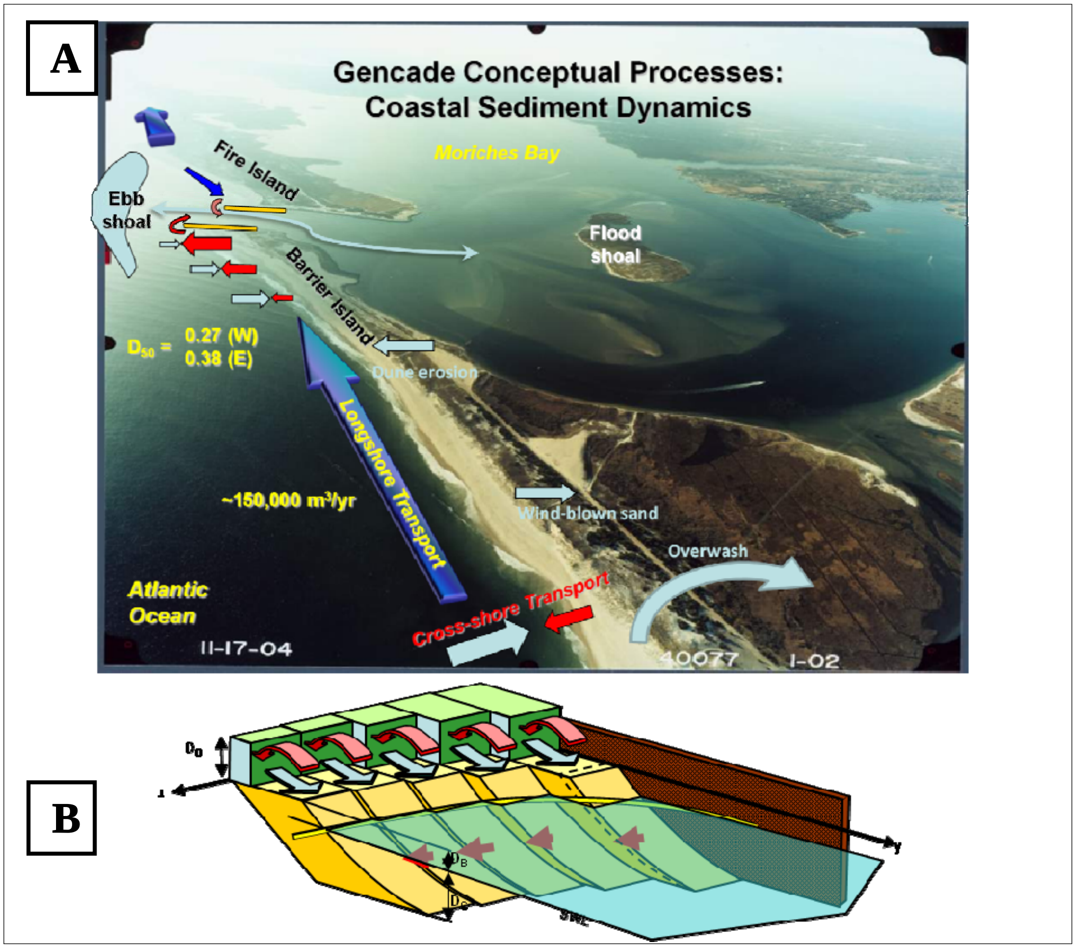

Figure 7. GenCade models regional shoreline change by calculating the longshore sediment transport across cells to provide profile volume change, and includes structures and inlet effects. A) A conceptual description of some of the processes included in GenCade; B) Illustration of how the model operates sediment transport and profile volume change on each cell in the grid.

Some of the assumptions implicit in GenCade are uniform profile evolution, waves are linearly transformed between wave station locations, and uniform bypassing and beach fill width. Because the parameters that define the beach profile (median grain size D50, berm crest, and depth of closure) are at present uniform and temporally fixed, profile evolution cannot include profile steepening or other cross-shore volumetric changes. Wave property changes between stations are linearly interpolated, and their range along the grid is evenly distributed over grid cells. This provides some sensitivity to the number of wave stations included in the grid, and to how well they represent any local wave transformation over topographic features. Beach

fills and bypassing rates are uniformly distributed, and therefore, the model cannot be used for beach-fill design purposes, rather only for planning volumes and reaches. The main defining assumption in the Inlet Reservoir Model is that the sand transported into reservoirs is controlled by an exponential equation that relates volume of the reservoir at that time to total elapsed time and a known equilibrium volume.

The model can be applied to evaluate different sediment management activities over long time scales. Because it has some control over the sediment flux in to and out of the region, sediment mass can be balanced between the separate projects occurring along the coast, and therefore the model can be applied to calculate future with-project sediment budgets. There are several attributes of a sediment budget that can be evaluated within GenCade including addition or removal of structures, dredging or mining volumes from channels or shoals, beach nourishments, sediment bypassing, and general shoreline and profile volume change under varying wave conditions. For sediment management optimization along St. Johns County, GenCade was used to optimize ebb shoal mining of sand and its subsequent use in the beach nourishment projects.

2 Calibration with Historical Measurements

To apply GenCade to a project site for application to future conditions, the model must first be calibrated (parameters adjusted) to known measured data. The calibration period applied a dataset from 1986 to 1999 to GenCade in the form of comparing shoreline change, magnitudes of sediment transport, and primarily through volumetric change. The standard procedure for numerical models is to apply the model twice over two separate time periods, once for calibration and again for model validation; however, the wave datasets necessary to complete validation were unavailable during the time of the study. Thus, the calibration process served as guidance in determining the potential accuracy in estimating future alternatives.

2.1 Model setup

The GenCade model domain for St. Johns County was one-dimensional and spans the length of the county. The grid consisted of 360 cells and started at cell 1 in the north with 1,000 ft in width, progressively decreasing in width down to 200 ft within the vicinity of the inlet, and increasing at the southern terminus back to 1,000 ft. The orientation of the grid was set parallel to the overall shoreline orientation of 165 degrees clockwise from true north with a southeasterly direction, assigning negative values for directions to the northwest and positive values to the southeast. Structures are the only other spatial features added to the grid setup, for which there are two fully-impounded terminal groins at the inlet, which function in GenCade as a type of jetty, and a seawall along St. Augustine Beach. The beach parameters that define the average equilibrium profile were determined based on the advice of Jacksonville District engineers and from a report by Taylor Engineering Inc (2010): an average berm height of 5.0 ft Mean Sea Level (MSL), a closure depth of 20 ft MSL, and an effective grain size of 0.2 mm (also determined by observations illustrated in the Study Area section).

In addition to the datasets listed above, GenCade requires a regional contour for any model domain that does not have a completely straight shoreline. The regional contour, similar to that in Genesis and Cascade, follows the overall orientation change in the coastline and is typically a well smoothed, coarsely resolved version of the initial shoreline used in the model. Smaller shoreline features, such as an ebb-tidal delta attachment location or a recession in shoreline near a structure, are not included in

the regional contour, or should be averaged. The purpose of the regional contour is to modulate the calculations on the shoreline such that they are relative to shore-normal, rather than grid normal. The result of including this feature is shoreline change that preserves large-scale undulations and curvature in the shoreline. For a smoothed representation of the St. Johns County shoreline, the -4 ft MSL contour was smoothed and used as the regional contour. Figure 8 illustrates the GenCade grid setup including the initial shoreline (green), regional contour (light blue), inlet bypassing locations (blue), seawalls (navy blue), and wave gages (red symbols). GenCade shows the wave gages on the model baseline, but these are located offshore at approximately 72 ft water depth.

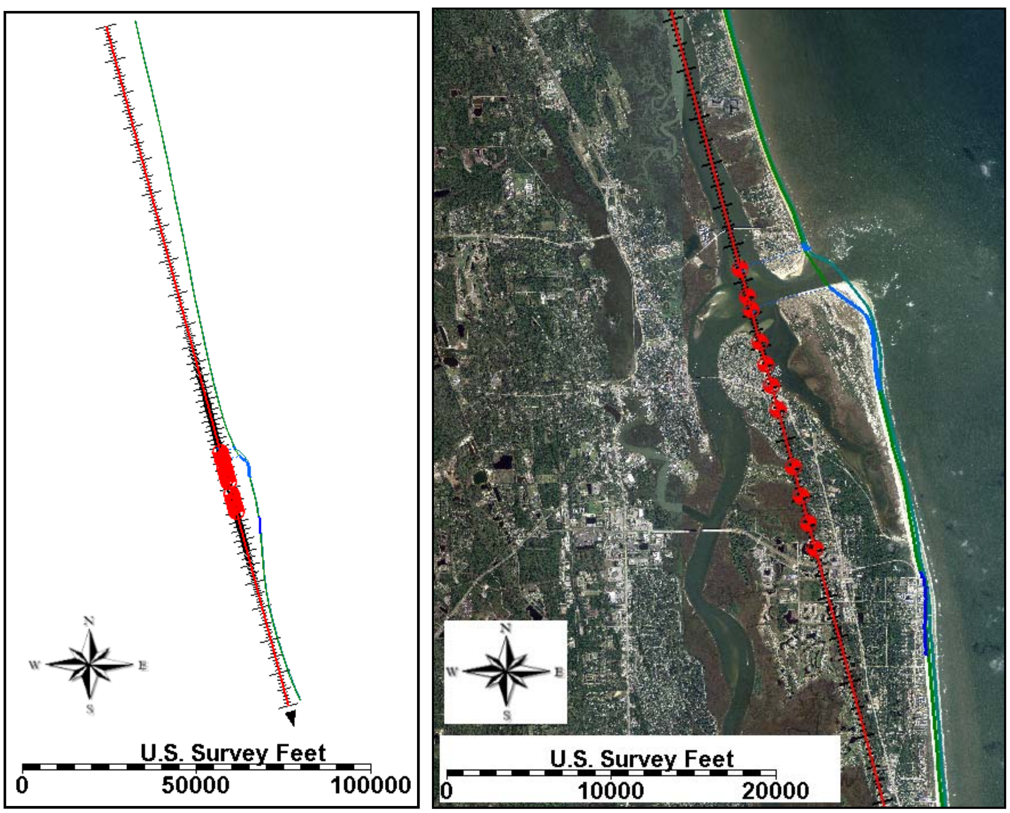

Figure 8. GenCade model grid (left); zoomed to grid near St. Augustine Inlet (right); regional contour is light blue, initial shoreline is green, inlet bypassing locations are blue, seawalls are navy blue, and wave gage locations are represented by red symbols represented on the grid.

GenCade also requires definition of the equilibrium volume for the inlet shoal features. The equilibrium volumes and coupling coefficients define the growth of these features and how sand is transported through the inlet system. For application to St. Augustine Inlet, the ebb-tidal delta was assumed to have an equilibrium volume of 40 million cu yd, as estimated by Walton

and Adams (1976) and using measured values (Figure 9), and 1.7 million cu yd for the flood-tidal delta (from a 1992 map; Carr-betts and Mehta 2001). The measured ebb-tidal delta volume from a 1998 bathymetric map is 35.5 million cu yd (above the 30-ft depth contour) as calculated using the plane nearshore contour method used by Dean and Walton (1973). Table 2 lists the relevant ebb-tidal delta volumes.

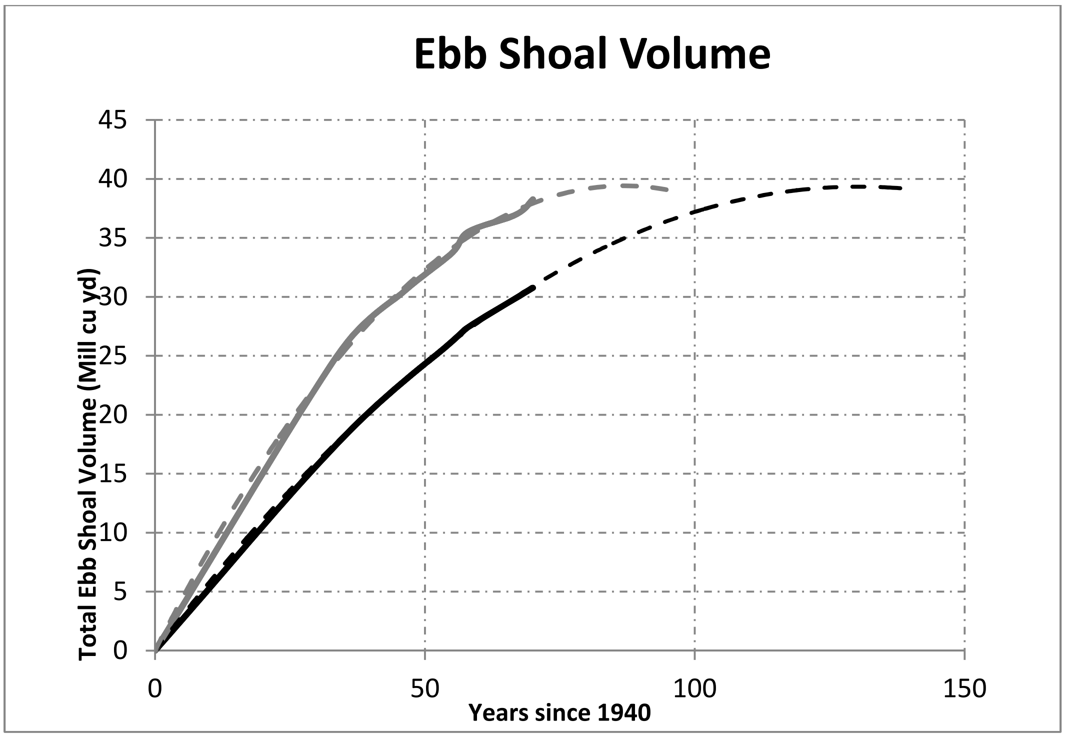

Figure 9. Reported Ebb Shoal Volumes (Taylor Engineering Inc. 1994; Beck and Legault, 2012) in the solid lines and extrapolated volumes in the dashed lines. Both the 26-ft and 30-ft contours were chosen as closure depths and so both were calculated. Approximately 40 million cu yd is the expected maximum volume.

Table 2. Measured ebb-delta volume of St. Augustine Inlet, Florida at the 30 ft contour (Legault et al. 2012).

Period	Volume (MILLION CU YD)
1986	30.4
1998	35.5
1999	35.9
2007	29.5
2010	30.9

2.2 Calibration

The calibration of GenCade requires some measured data as input, and additional measured data from a separate time period with which to compare and adjust parameters to produce a close representation of shoreline position, volumetric change, and sediment transport rates. Input data for this calibration period were the initial shoreline from a 1986 mean high water (MHW) measurement of vertical beach profiles, dredging volume and removal dates, sediment placement in the form of nearshore bypassing and beach nourishment data, and a known background erosion rate (Inlet Management Plan, Taylor Engineering Inc. 1996) at the boundaries. Table 3 lists the dredging and nourishment history used as input for the 1986-2005 time period.

Table 3. Dredging and nourishment input data for 1986 – 2007, St. Johns County, FL.

Date	Volume Dredged, cu yd	Nearshore Placement, cu yd	Beach Fill, cu yd
1986	121,247	nearshore	-
1996	257,649	-	257,649
1997	130,000	-	130,000
1998	130,000	-	130,000
2001	2,200,000	-	2,200,000
2002-03	2,000,000	-	2,000,000
2005	2,800,000	-	2,800,000

Calibration began with reproducing the estimated average, net transport rates as reported by the Inlet Management Plan (Inlet Management Plan, Taylor Engineering Inc. 1996), for the St. Johns County area, which range from 200,000 to 250,000 cu yd/year at the northern boundary of the study area, given that net transport is directed to the south. As suggested in the GenCade User's Manual (Frey et al. 2012), Calibration refers to the procedure of determining values of adjustable coefficients that condition the model to reproduce changes in shoreline position measured over a certain time interval. In the case of GenCade, calibration also includes conditioning the model to reproduce known changes in inlet reservoir volumes. Sediment transport rates are calculated by the GenCade (Hanson 1989; Frey et al. 2012) equations for longshore transport, Q, and are calculated as:

$$Q = \left(H^2 C_g\right)_b \left(a_1 \sin 2\alpha_{bs} - a_2 \cos\alpha_{bs} \frac{\partial H}{\partial x}\right)_b \qquad (1)$$

where C_g is the wave group velocity (m/sec), α_{bs} is the angle of significant breaking wave crests to the shoreline, the subscript b denotes the breaking condition, H is the wave height (m), and x is the cross-shore distance. The non-dimensional parameters a_1, and a_2 are given by:

$$a_1 = \frac{K_1}{16 / \left(\frac{\rho_s}{\rho} - 1\right)(1-p)1.416^{5/2}} \tag{2}$$

$$a_2 = \frac{K_2}{8 / \left(\frac{\rho_s}{\rho} - 1\right)(1-p)tan\beta 1.416^{5/2}} \tag{3}$$

where K_1 and K_2 are calibration parameters, ρ_s and ρ are the densities of the sediment (quartz sand) and water (kg/m3), respectively, p is the sediment porosity, and $tan\beta$ is the average bottom slope from the shoreline to the depth of longshore transport, D_{LT}. The factor 1.416 is used to convert from significant to RMS wave height."

The first step in the calibration procedure is to determine *K*1 by reproducing known transport rates along the grid. Next, *K*1 may be further modified to match measured shoreline or volume change. Finally, the *K*2 coefficient can be adjusted to modify the shoreline change downdrift of structures and other sediment sources or sinks (i.e. inlets, beach fills). Sediment transport rates in GenCade are largely controlled by input wave parameters and the longshore sediment transport coefficients *K*1 and *K*2.

WIS hindcast wave data (Waves Information Study, http://frf.usace.army.mil/wis/) were used for the calibration period, and a 20 year period from 1980-1999 was duplicated for the 50-year optimization alternatives. Calibration using the WIS waves was conducted over the 13 year period from a single hindcast wave station (from 1986 to 1999; WIS Hindcast Station ST63417) across the entire model domain. The use of the WIS hindcast for St. Johns County reproduced the documented transport magnitudes and net directions. Values of 0.6 and 0.4, for *K*1 and *K*2 respectively, were found to best represent the documented average net and gross transport rates over relatively straight sections of coast (i.e., Vilano Beach). Initial calculated sand transport rates from the first calibration of the *K* values are given in Figure 10.

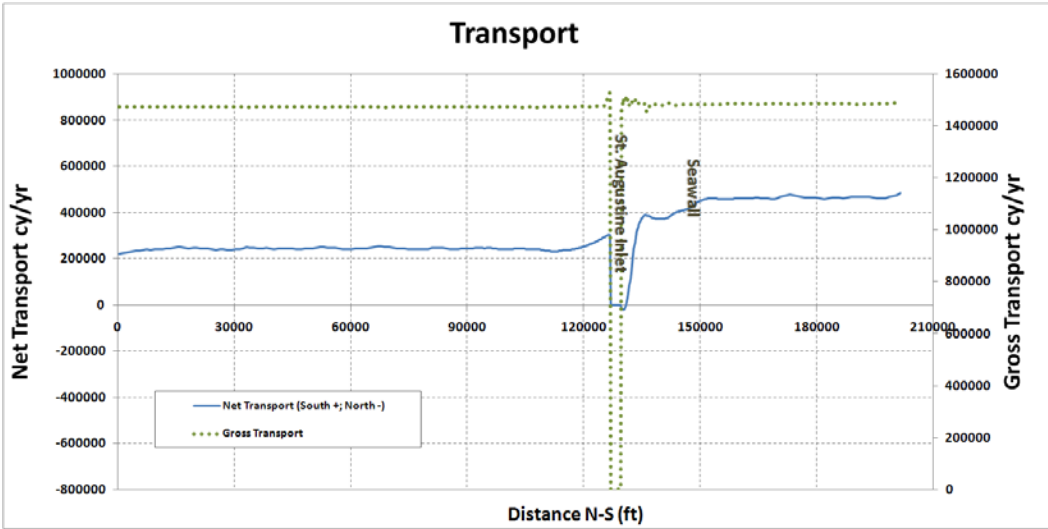

Figure 10. Initial calibration of the calculated net sand transport rate for the calibration period of 1986-1999.

These calculations resulted in a median net transport rate of 230,000 cu yd/year north of the inlet and 390,000 to 450,000 cu yd/year south of the inlet, and a gross transport rate of 1,500,000 cu yd/year. However, a known reversal in net transport exists from the northern tip of Anastasia Island down to St. Augustine Beach, and the simplified wave model used in GenCade does not capture this reversal. This is likely due to poor transformation of deeper water waves (GenCade assumes plane and parallel contours for wave propagation) and the lack of representation of the ebb-tidal delta that would refract much of the wave energy over that area of shoreline. To resolve this, WIS waves were manually modified (adjusted 5-15 degrees toward the north) from R123 to R132 to account for the refraction of waves around the ebb-tidal delta of the inlet. The adjustment of five degrees occurred at R123 and R132, and the degree of change increased toward 15 degrees near R127. Profiles R127 and R128 are located at the prominent headland where the ebb-tidal delta attaches to the shoreline (Figures 2 and 6). Wave refraction around this area was found to drive the sediment transport to the north under all wave conditions (Beck and Legault 2012). The result of this modification, seen in Figure 11, more correctly represents the documented trend of variations in net transport and agrees with the total volumetric change as discussed in the following paragraphs. Specifically, net transport is approximately 200,000 cu yd/yr over much of the stretch of coastline with little shoreline orientation change (particularly to the north). Gross and net transport changes significantly between the inlet and the seawall where there are now gradients in wave energy.

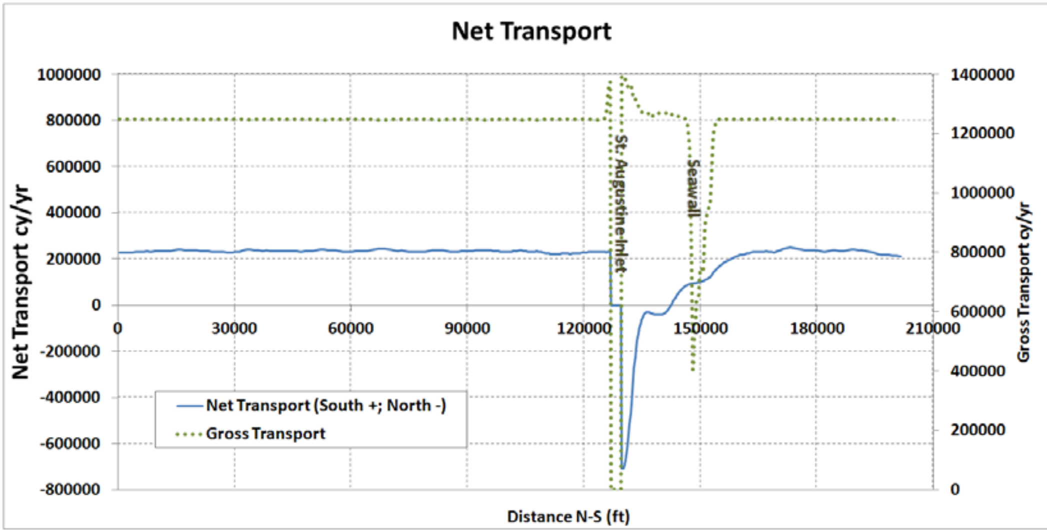

Figure 11. Final calibration of the calculated net sand transport rate for the calibration period of 1986-1999, including modified waves over the downdrift (south) side of the inlet from R123-R132.

Parameters that define the inlet in the model domain, St. Augustine Inlet, were defined and tested for sensitivity to functions including inlet bypassing location and terminal groin permeability. Because all dredging occurs in the ebb-tidal delta portion of the inlet shoals, all of the ebb delta volume was kept in one morphologic feature within the Inlet Reservoir Model to simplify calculations. Total volume for the ebb-tidal delta was calculated for 1986 as approximately 30.5 million cu yd, and a total equilibrium volume was set to 40 million cu yd. The bypassing, or exchange, of sediment between the Inlet Reservoir Model and the adjacent beaches is calculated over discrete reaches of shoreline, and these reaches are identified in the model as being to the left or the right of the inlet of question. Potential bypassing to Vilano Beach updrift of the inlet (or, to the left) does not appear to be significant in that there are no notable shoreline, or morphologic, features to indicate active connectivity. Therefore, the inlet left-bypassing location was set to the first adjacent cell. Downdrift of the inlet (to the right), the beach at Anastasia State Park protrudes seaward over a significant alongshore distance due to the bypassing patterns of the inlet. Therefore, the right bypassing location covered 26 cells (~6,500 ft) from the jetty to the end of the protruded headland. Figure 12 shows the locations of bypassing adjacent to St. Augustine Inlet.

Permeability of the terminal groins (called jetties in GenCade) for the calibration period was estimated to be 80 percent for the north jetty and 30 percent for the south jetty (when not buried). These values are based on

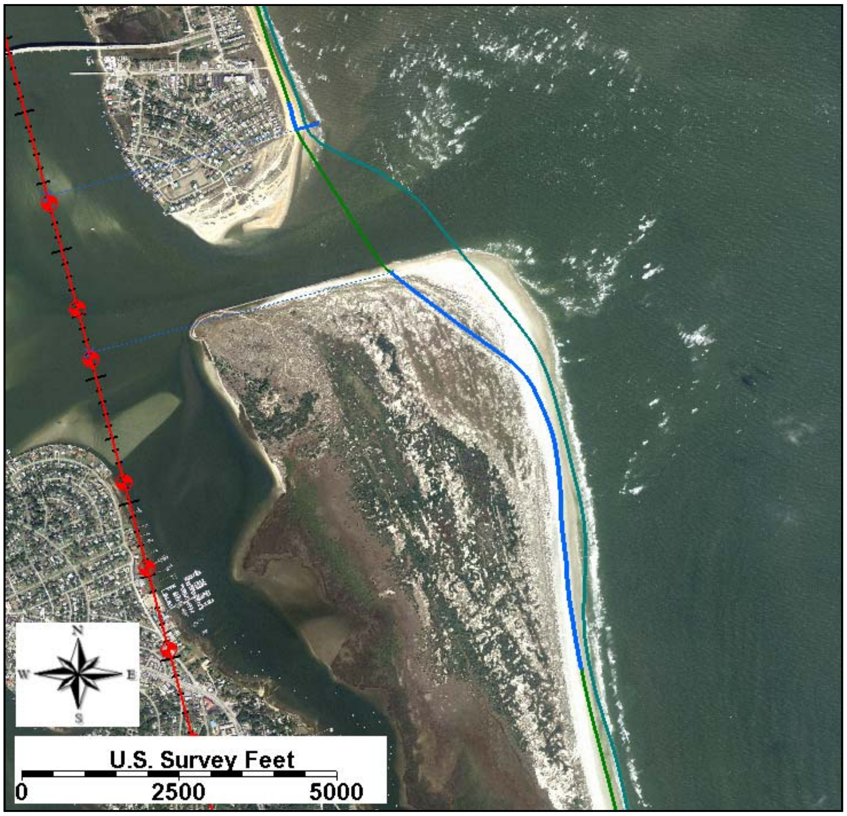

Figure 12. Bypassing locations along the grid are illustrated in blue over the initial shoreline (green).

observations at both groins, where the northern groin is typically buried and not functional whereas the south terminal groin defines the boundary between the 60 ft deep channel and the barrier terminus. In addition to groin permeability, a bypassing coefficient for each side of the inlet was calibrated to represent the capacity of the adjacent shoreline volume to transport sand in to, and accept sand from, the inlet reservoir system. A large value was estimated for the downdrift attachment area to represent the large bypassing signal found in the accretion of the headland (the northern end) at Anastasia Island, as is typical of a mixed-energy drumstick barrier island. This value is sensitive to the present morphologic shape of the ebb-tidal delta, the bypassing pattern, and general morphodynamics of the inlet for the time period, and, will therefore change during different time periods as the varying inlet morphodynamics are not included in the model. These bypassing coefficients were set to 0.5 for the north coefficient and 70 for the south coefficient. As a result, final inlet reservoir volumes for the calibration test had a difference of -36 percent from the measured volume.

Lateral boundary conditions (LBC) at the north and south boundaries of the grid were set to the Moving LBC option to allow unmitigated migration

of the shoreline based on ambient alongshore sediment transport rates at the boundaries. No additional erosion was applied over the forcing period for the northern and southern boundaries as a part of the boundary conditions (BC). Measured profile volume change was compared for the 13-year simulation form 1986-1999 as shown in Figure 13.

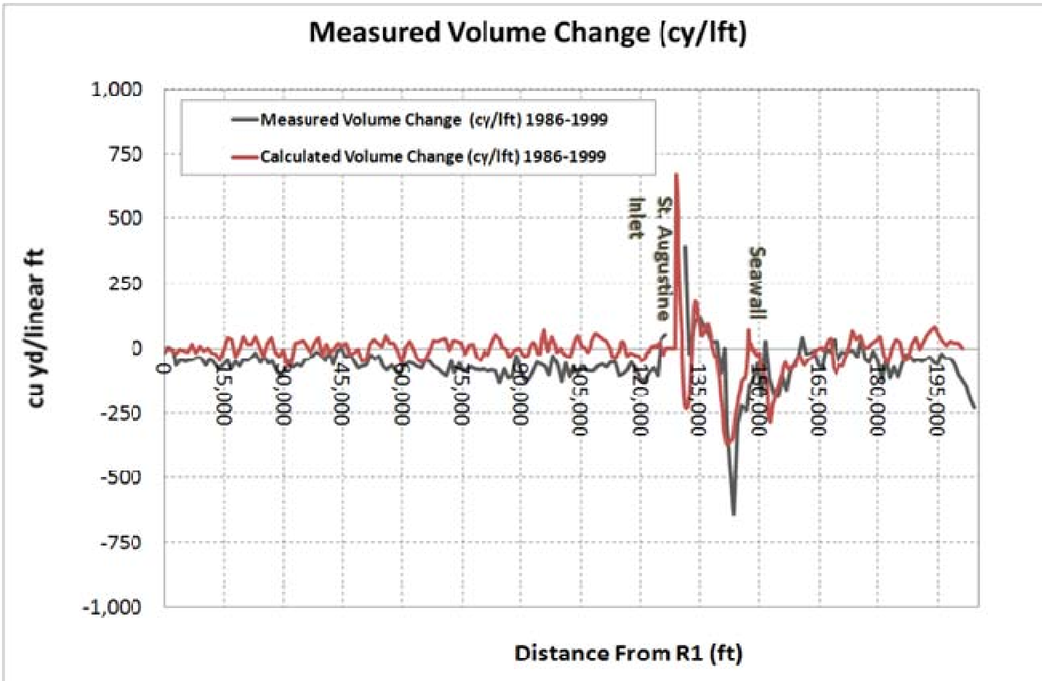

Figure 13. Measured vs. calculated profile volume change for the calibration period of 1986-1999. Note that this first test does not include the background erosion rate, thus the calculations (red) are slightly greater than measured (black) at most cells.

The overall calculated trend of profile volume accretion rates compared well to the measured rates at complicated regions including the inlet-adjacent shoreline. However, because GenCade cannot capture all of the known processes of sediment transport, including cross-shore processes, the well-documented background erosion rate (Taylor Engineering Inc. 1994) was not captured in the calculated results. Reasons for the poor representation of the background erosion rate could be due to a number of processes that are presently not represented in GenCade, including the inability to represent varying beach profile shapes and varying mean sand sizes (see study area discussion about alongshore grain size variation). To summarize beach profiles for the region (Legault et al. 2012), Beaches north of the inlet are steeper and narrower from dune to shoreline, beaches along St. Augustine beach (immediately south of the inlet) are gently sloping and wide, and further south along St. Augustine and Crescent Beaches, the profiles are gently sloping and range greatly in beach width. To account for

this sediment sink, a background erosion rate of 80 cu yd/hr (or, -700 K cu yd per year) was added to the entire domain. This erosion rate equates to approximately 3.5 cu yd/lft(linear foot) every year, a substantially smaller number when compared to the volumes of beach fills placed along the study area. Although representing the background erosion rate in this way was not the optimal means of representing this process, it was sufficient and necessary to accurately represent the total sediment budget, which is utmost priority in this type of study. Figure 14 illustrates the new calibration including the background erosion rate. Table 4 lists the Normalized Root Mean Square Error (NRMSE), the correlation coefficient for the measured and computed volume change, and the percent correlation of erosion or accretion.

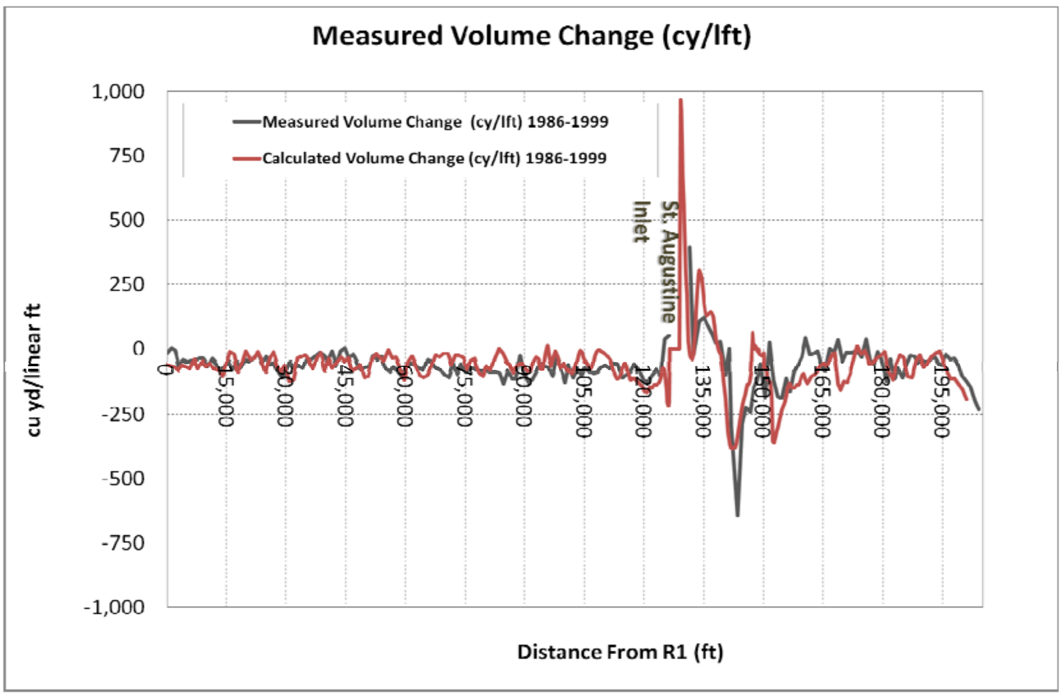

Figure 14. Measured vs. calculated profile volume change for the calibration period of 1986-1999 that includes the background erosion rate.

Table 4. Statistics for the measured and computed volume change.

NRMSE	6.8 %
Correlation Coefficient	0.61
Pattern Correlation (Erosion/Accretion)	93.9%

Shoreline response of the calibrated model is shown in Figure 15, for the years 1993 and 1999. Taylor Engineering Inc. (2010) recognized the

difficulty of comparing a MHW shoreline that was derived from the zero crossing on profiles, and comparing them to a shoreline from a generalized profile that may have a very different shape. Volume is conserved in GenCade, and for a study of this type that seeks to optimize placement locations of given volumes of mined sand, volume change should be the priority means of calibration. Therefore, volume change was used as a first estimate of model calibration, and shoreline change was qualitatively analyzed for known erosional and accretional trends. Volumetric change more accurately represents the changes that are occurring along a study region. Shoreline recession is captured along the northern Ponte Vedra and Vilano Beaches, and Crescent Beach to the south. These results are to be expected because the beach profiles there are best represented by the berm height, median grain size D50, and depth of closure parameters as used in this study. Beach profiles near St. Augustine Inlet and Matanzas Inlet at the southern terminus are influenced by the presence of shoals and therefore tend to have a shallower shape and do not accurately represent the magnitude of shoreline change. Overall, shoreline trends compare well with the measured trends.

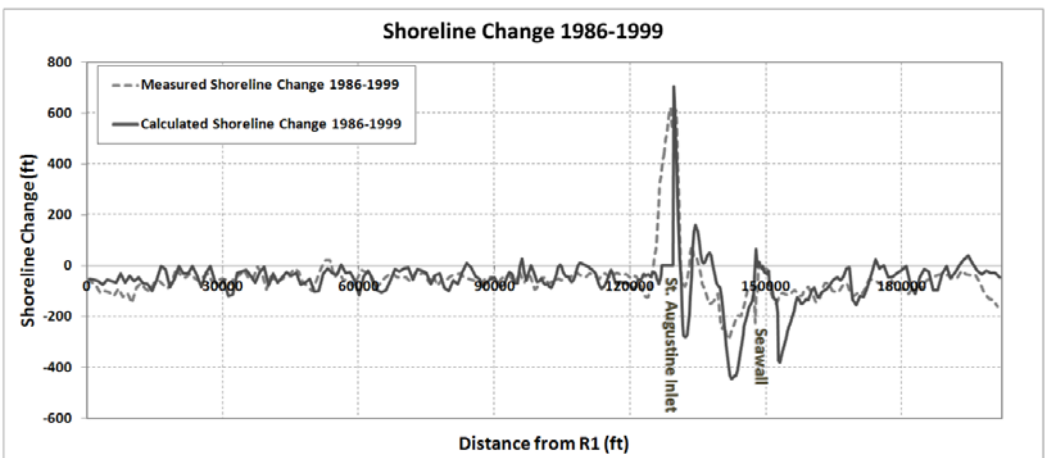

Figure 15. Measured vs. calculated profile shoreline change for the calibration period of 1986-1999 that includes the 1993 and 1999 shoreline positions. Erosional and accretional trends are bracketed and highlighted.

To summarize, calibration to transport rates and directions, shoreline change rates, and general geomorphic response was successful. Sensitivities found in GenCade proved to be inlet and structure (seawall) related, or connected to known, large-scale events, typically beach nourishments. The most significant natural geomorphic observation is the growth of the attachment location of the ebb-tidal delta of St. Augustine Inlet. Table 5 lists the final calibration parameters set in the model.

Table 5. Calibrated GenCade model feature coefficients determined for the 1986-1999 modeled time period.

Feature	Value	Feature	Setting
K1 Coefficient	0.6	Background Erosion Rate (Cross-shore Losses for Entire Grid)	-80 cu yd/hr
K2 Coefficient	0.4	Left (north) Lateral Boundary Condition	Moving; 0 ft per simulation
D50 (mm)	0.2	Right (south) Lateral Boundary Condition	Moving; 0 ft per simulation
Berm Height (ft, MSL)	5	Inlet Left (north) Jetty Bypassing Coefficient (JBCL)	0.5
Depth of Closure (ft, MSL)	20	Inlet Right (south) Jetty Bypassing Coefficient (JBCR)	70
Ismooth (averaging window)	1	Inlet Left (north) Jetty Porosity	0.8
Time Step (hr)	0.0625	Inlet Right (south) Jetty Porosity	0.3

3 Optimizing Sediment Management

The primary goal of this study was to determine an optimal sediment management plan for the Jacksonville District for the major sediment sources and sinks in St. Johns County; specifically, the St. Augustine Inlet ebb-tidal delta and the two adjacent Shore Protection Projects. Based on the successful calibration of GenCade including dredged channel infilling and placement for the 1986-1999 dataset, GenCade was applied with confidence to calculate future with-project alternative sediment pathways between the inlet and the adjacent shorelines. An optimization of sand mining from the inlet and placement on adjacent beaches was determined, first, through identifying the sustainable maximum dredging volume from the inlet and associated interval, and second, through nourishment volumes and placement reach. Ultimately, the dredging volumes and intervals were coupled with the necessary placement volumes and intervals to reach a long-term, sustainable management of these two features over a 50-year planning horizon.

3.1 Methodology: Optimization with historical data

To optimize the volume of sand mined from the inlet with associated placement locations on the adjacent beaches, historical data were analyzed to understand how the inlet-adjacent beach system has responded in the past. Parameters to be optimized were the range of dredged volume and potential dredging intervals. The ranges of each optimized parameter must first be determined by basic engineering constraints that follow the “Engineering with Nature” concept recently adopted by USACE (EwN, 2012). The USACE defines Engineering with Nature (EwN) as “the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental and social benefits through collaborative processes”. This study formulated a conservative EwN approach to constrain all modeled alternatives to the measured capacity of an ebb-tidal delta to maintain its natural behavior, primarily under engineered conditions.

In Report 2, Beck and Legault (2012) modeled the capacity of the mined ebb-tidal delta to maintain its bypassing potential and found that dredging can modify the ebb-tidal delta planform area and volume to such as degree

as to disturb the inlet system's functionality. In Figure 16, four alternatives modeled in Report 2 are shown with varying sediment volumes removed from the permitted dredging template. They described a threshold in how much sand can be removed from the permitted dredging template over the ebb-tidal delta before the system is modified beyond a morphodynamic equilibrium, after which, the navigation channel will rapidly migrate and the ebb-tidal delta volume will recover or decrease at unpredictable rates. They defined the highest value of the volume of material that can be removed from the ebb-tidal delta, which was determined to be approximately four million cu yd based on the available sediment material within the dredging area (Figure 17).

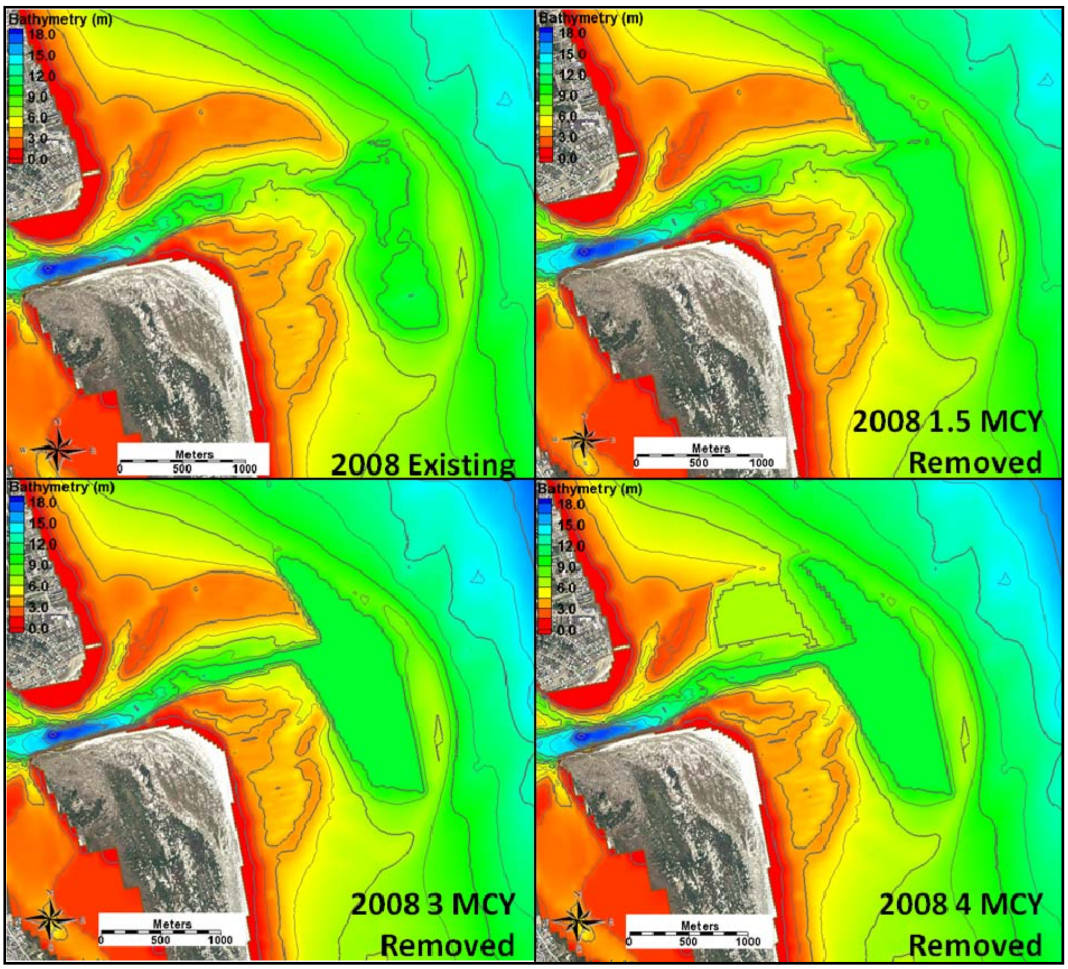

Figure 16. Modeled alternatives from Report II that compared the 2008 existing condition and the three dredging scenarios (from Beck and Legault, Report 2 2012).

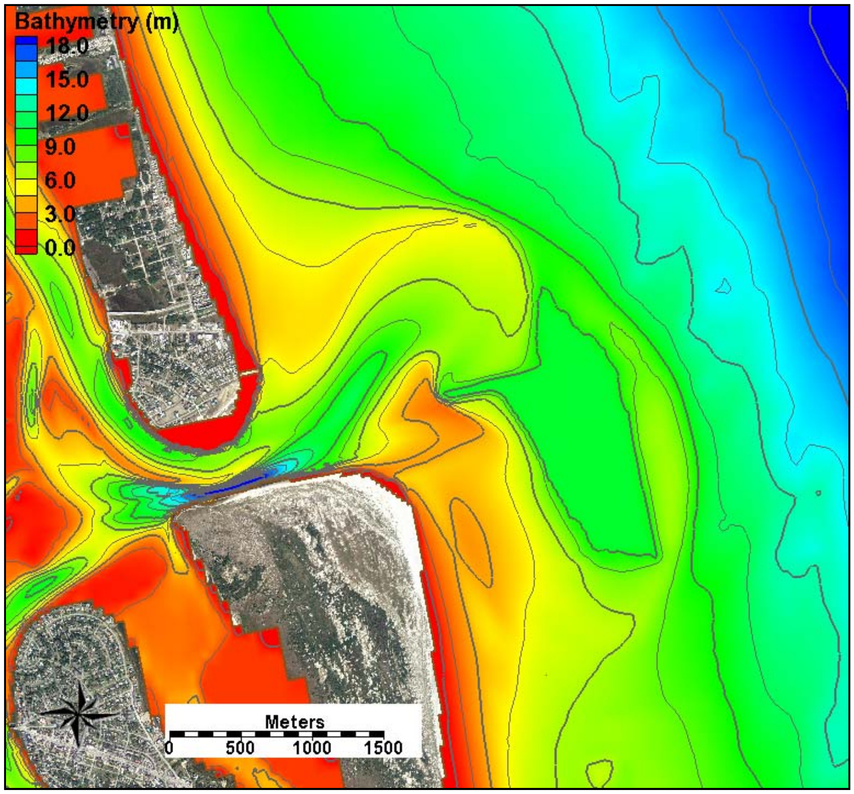

Figure 17. Calculated morphologic result of 1.4 year simulation of the '2008 4 MILLION CU YD Removed' dredging scenario (Beck and Legault, Report 2, 2012).

To ensure that ebb-tidal delta volume does not fluctuate below recent near-equilibrium levels found in the 1998 bathymetry, measured ebb-tidal delta volume change rates from 1998 to 2010 were compared to determine how the shoal recovered after recent dredging cycles. Prior to ebb delta mining, the inlet accreted at different rates each year, averaging 400,000 cu yd of accretion per year from 1986 to 1998 (Legault et al. 2012). The ebb-tidal delta is asymptotically approaching an equilibrium volume as predicted by the inlet reservoir model using the equilibrium volume of ~40 MCY illustrated in Walton and Adams (1976) (see Figure 9). St. Augustine Inlet was approaching the "dynamic equilibrium" for volumetric change at the inlet in 1999, prior to ebb-shoal mining. Kraus (2001) describes dynamic equilibrium as "a condition in which a system displays slightly different average states through time. The morphologic feature is in a state of near-balance, in spite of changes taking place within it (for example, beach shape under typical waves that is gradually moving toward equilibrium with those waves)…the terms dynamic equilibrium and quasi-equilibrium are sometimes employed." Table 6 lists ebb-tidal delta volume-change rates for St. Augustine Inlet before and after the 2001-2003 and 2005 dredging events.

Table 6. Ebb-tidal delta volume change rates for St. Augustine Inlet before and after the 2001-2003 and 2005 dredging events.

Interval	Volume Change, cu yd (With Dredged Volume)	Volume Change, cu yd (Without Dredged Volume)	Volume Change Rate, cu yd/yr (Without Dredged Volume)
1986 - 1998/1999	5,071,250	5,071,250	405,700
1998/1999 - 2003	3,434,151	1,065,849	236,855
2003 - 2005 pre dredge	525,976	525,976	262,988
2005 - 2005 post dredge	3,449,089	-449,089	-449,089
2005 post - 2007	790,051	790,051	526,701
2007 - 2008	633,712	633,712	633,712
2008 - 2010	780,589	780,589	446,051

Immediately following each ebb-delta mining activity, the ebb-tidal delta experienced a change in accretion rates. The disrupted accretion rate increased logarithmically each year back to its natural potential accumulation rate. This logarithmic increase is shown in Table 7 and in Figure 18. Another dredging event disrupts this response, and reset the total cumulitive recovery rate. To detrend the accretion of the ebb-tidal delta attributed to responsive infilling from Table 7, the volume change rates are cumulitively summed from 1998 to calculate the rate at which the volumetric change rate was decelerating. Table 3 lists the cumulative, long-term average of the ebb-tidal delta volume-change rate. Figure 18 shows a bar graph plot of the cumulative volume change rates. Figure 19 illustrates this decelerating rate as a logarithmic function of time, where the cumulative infilling rate approaches an equilibrium value of volumetric change, ~400,000 cu yd/yr.

Table 7. Cumulative, long-term average ebb-tidal delta volume change rate (cu yd/yr) from 1998.

1998/1999 - 2003	236,855
2003 - 2005 pre dredge	265,304
2005 - 2005 post dredge	175,806
2005 post - 2007	241,598
2007 - 2008	285,167
2008 - 2010	304,281

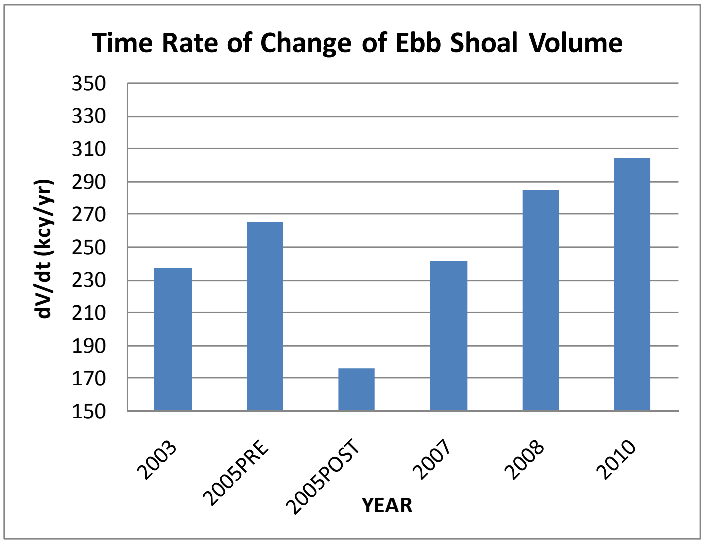

Figure 18. Cumulative, long-term average of the ebb-tidal delta volume-change rate for each measurement period. The 2003 and 2005 post measurements both follow two ebb-delta mining events.

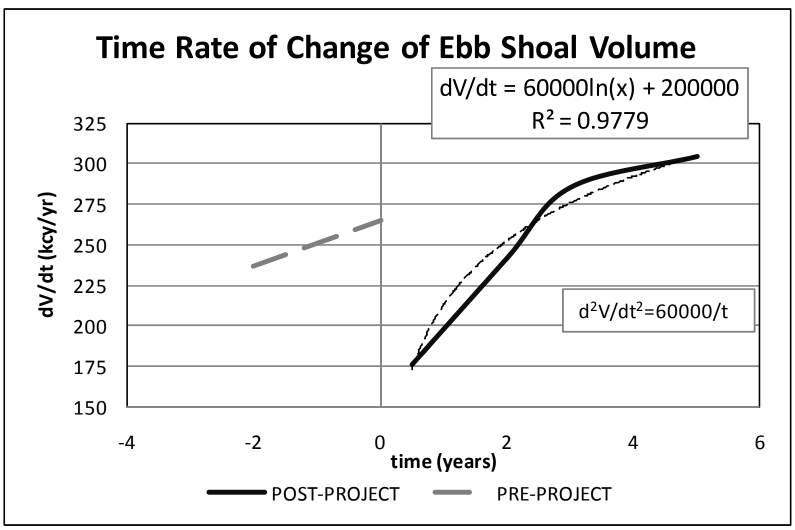

Figure 19. Deceleration rate of the cumulative (black dashed line), long-term average of the ebb-tidal delta volume change rate for each measurement period. The 2003 post dredging period and the 2005 post dredging periods are separated in dashed-gray line (2003) and black (2005).

Using this logarithmic rate of accretion that was derived from historical data, ebb-tidal delta growth can be estimated through time for different dredging quantities and dredging intervals. For instance, if the shoal is mined every 10 years, the volumetric change rate will increase over each 10 years as seen in Figure 20; however, the average rate overall will be ~300,000 cu yd/yr. This rate is then applied to a linear calculation of

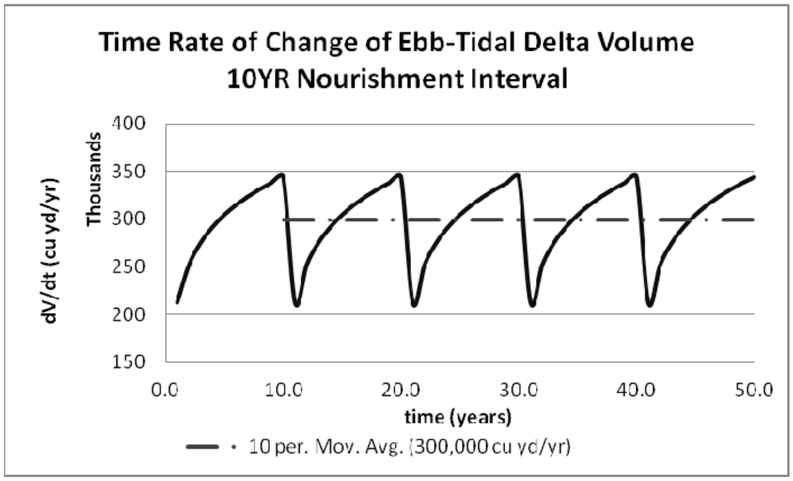

Figure 20. Time rate of change of the ebb-tidal delta volume in a hypothetical 10-year period (10 per. Moving Average) mining scenario.

volumetric change of the ebb-tidal delta for 5-year and 10-year ebb-delta mining intervals in Figure 21. The logarithmic calculation of volume change rates was not applied because the changing rate was only measured for a 5-year period, which should not be extrapolated over longer time scales. The total volume change over 50 years only needed volume change for the 5-, 7-, and 10-years periods. The figure illustrates that for different volumes removed at each time interval, there is a potential for the overall ebb-tidal delta to accrete, maintain volume, or decrease beyond its potential to recover. For the 50-year planning horizon, ebb-delta mining scenarios that result in either a no-change (maintains present equilibrium volume) or accretional pattern are chosen as ‘Dredging Intensity’ alternatives for GenCade.

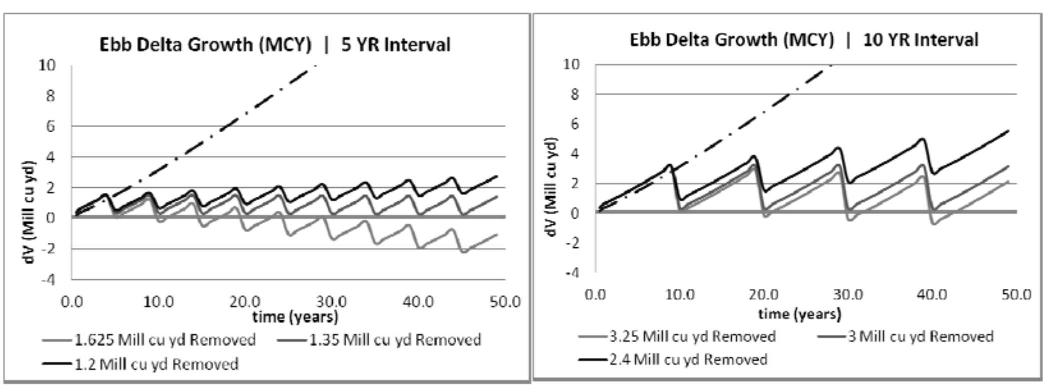

Figure 21. Time rate of change of the ebb-tidal delta volume in a 5-year (left) and a 10-year (right) mining scenario.

3.2 Dredging intensity

The sediment management practice for St. Johns County described in this report only considers the St. Augustine Inlet ebb-tidal delta as a sediment source. Though there are outside sources such as oblique, offshore shoals, the present management plan is focused on the presently authorized projects, which are the inlet and the St. Augustine Beach SPP. The first set of alternatives for the 50-year planning horizon includes all of the dredging scenarios described in the above methodology section that resulted in a increase in ebb-tidal delta volume. Table 8 lists the quantities and dredging intervals of each scenario. For all alternatives, the beach placement volume is held constant for location and length. Alternatives A1 and A2 have varying beach fill volumes from one million cu yd to the maximum of 1.35 million cu yd. Alternatives A3 and A4 place the maximum dredged volume for the 7 and 10-year dredging intervals.

Table 8. Dredging intensity scenarios considering equal or accretional status of the ebb-tidal delta.

Scenario	Dredged Volume	Dredging Interval	Beach Placement Volume	Beach Placement Location & Length
Alt A1	1.0 Million cu yd	5 Years	1.0 Million cu yd	T137a – R151 (15,000 linear feet)
Alt A2	1.35 Million cu yd	5 Years	1.35 Million cu yd	T137a – R151 (15,000 linear feet)
Alt A3	2.0 Million cu yd	7 Years	2.0 Million cu yd	T137a – R151 (15,000 linear feet)
Alt A4	3.0 Million cu yd	10 Years	3.0 Million cu yd	T137a – R151 (15,000 linear feet)

Since the modeled scenarios are long-term projections, there is a great uncertainty between the calculated volume change near the inlet for the 10 years representing the calibration period and a 50-year forecast which does not consider the morphodynamics of an inlet. To account for the unknown morphologic evolution of the inlet, one parameter was modified to address the bypassing capacity of the inlet over long time periods. The bypassing coefficient for the right (south) side of St. Augustine Inlet was reduced to 2.0 because the calibration coefficient predicted unrealistic modeled shoreline change in the vicinity of the inlet. This reduction represented a decrease in bypassing from the adjacent south beach to the inlet. Table 9 lists the parameters modeled in the alternative scenarios.

Table 9. GenCade model feature coefficients applied for the 50-yr alternatives.

Feature	Value	Feature	Setting
K1 Coefficient	0.6	Background Erosion Rate (Bypassing Rate)	-80 cu yd/hr
K2 Coefficient	0.4	Left (north) Lateral Boundary Condition	Moving; 0 ft per simulation
D50 (mm)	0.2	Right (south) Lateral Boundary Condition	Moving; 0 ft per simulation
Berm Height (ft MSL)	5	Inlet Left (north) Jetty Bypassing Coefficient (JBCL)	0.5
Depth of Closure (ft MSL)	20	Inlet Right (south) Jetty Bypassing Coefficient (JBCR)	2
Ismooth (averaging window)	1	Inlet Left (north) Jetty Porosity	0.8
Time Step (hr)	0.0625	Inlet Right (south) Jetty Porosity	0.3

The measured ebb-tidal delta volume for St. Augustine Inlet in 2010 was 30.9 million cu yd (see Table 2), the starting value used in the simulations. Alternatives representing various dredging volumes and intervals were selected based on maintaining the ebb delta volume as shown in Figure 21. Alternatives were based on a percentage of the equilibrium ebb-tidal delta volume (Figure 21). Results of the simulations indicated that only Alternatives A2 and A3 lost volume over the 50-year simulation, both less than three percent. A comparison of performance of the ebb-delta recovery of these alternatives is summarized in Table 10 and shown in Figure 22. Alternative A1 resulted in significant growth of the ebb delta. Removing two million cu yd (Alternative A3) on a 7-year interval and three million cu yd (Alternative A4) on a 10-year interval resulted in a near static equilibrium volume of the ebb delta.

The performance of volume retention within beaches maintained by the USACE (SPPs) was analyzed in separate sections of shoreline. Regions along the lateral boundaries were not considered in this analysis. It is important to note that the GenCade model does not take into consideration any other added sand in the form of beach fills to the updrift and downdrift counties. Therefore, adjacent beaches on the boundaries experience net erosion as defined in the calibration period, and no additional sediment was added from other regional projects. The nearest regional beach placement project to the study area is in Jacksonville Beach, ~30 miles to the north in Duval county. The sections analyzed included the Vilano Beach Nourishment Reach (R109-R120), Anastasia State Park (inlet adjacent, R123-R128), and St. Augustine Beach (R132-R151). Volume changes and their relative percent difference from total profile volume for the three reaches are shown in Table 11.

Table 10. Final ebb-tidal delta volume of each 50-year simulation and the percent difference.

Scenario	Final Volume (cu yd)	% Difference
Alt A1	32,485,116	5.10%
Alt A2	30,019,068	-2.88%
Alt A3	30,473,748	-1.41%
Alt A4	31,942,946	3.34%

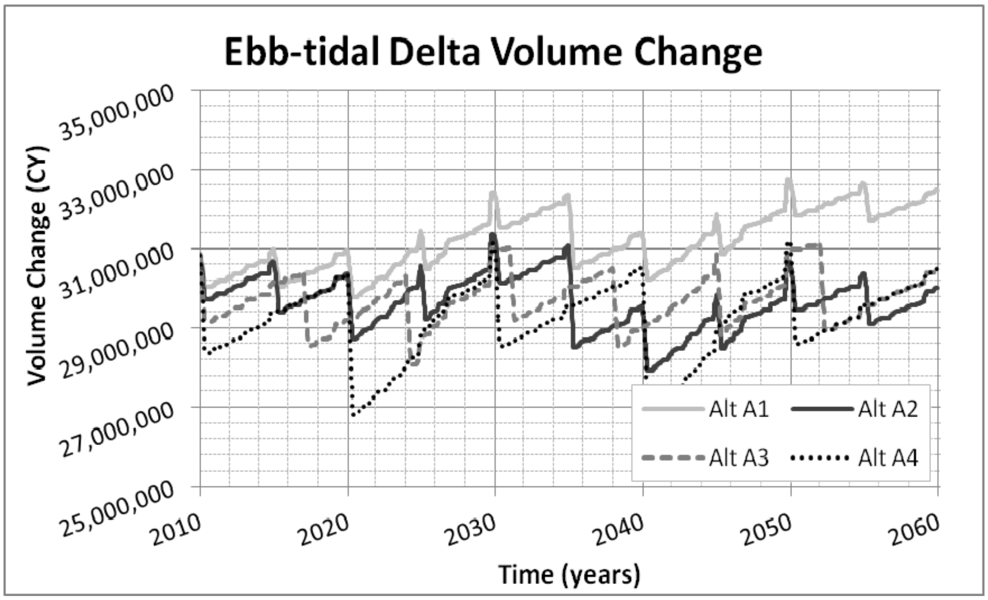

Figure 22. Time-series plot of the ebb-tidal delta volume change for Alts A1-A4.

Table 11. Final beach profile volume change (cu yd) of each 50-year simulation and the relative percent difference from the total profile volume (from R-Monument to -20 ft MLW) which has an arbitrary elevation per profile.

Shoreline Reach	A1		A2		A3		A4	
	CU YD	%	CU YD	%	CU YD	%	CU YD	%
Vilano Beach	-802,066	-8.7%	-1,007,726	-11.0%	-1,076,271	-11.7%	-918,879	-12.6%
Anastasia State Park	819,196	5.7%	559,732	3.9%	504,139	3.5%	853,673	3.4%
St. Augustine Beach	-6,034,964	-42.9%	-4,311,594	-30.6%	-2,504,689	-17.8%	-3,305,699	-24.7%

Figures 23 and 24 illustrate the results of the Alternatives A1 through A4, plotted over the grid domain and aerial photo to illustrate the location of structures and the inlet. Shorelines in green represent the initial shoreline, and the red line is the final calculated shoreline.

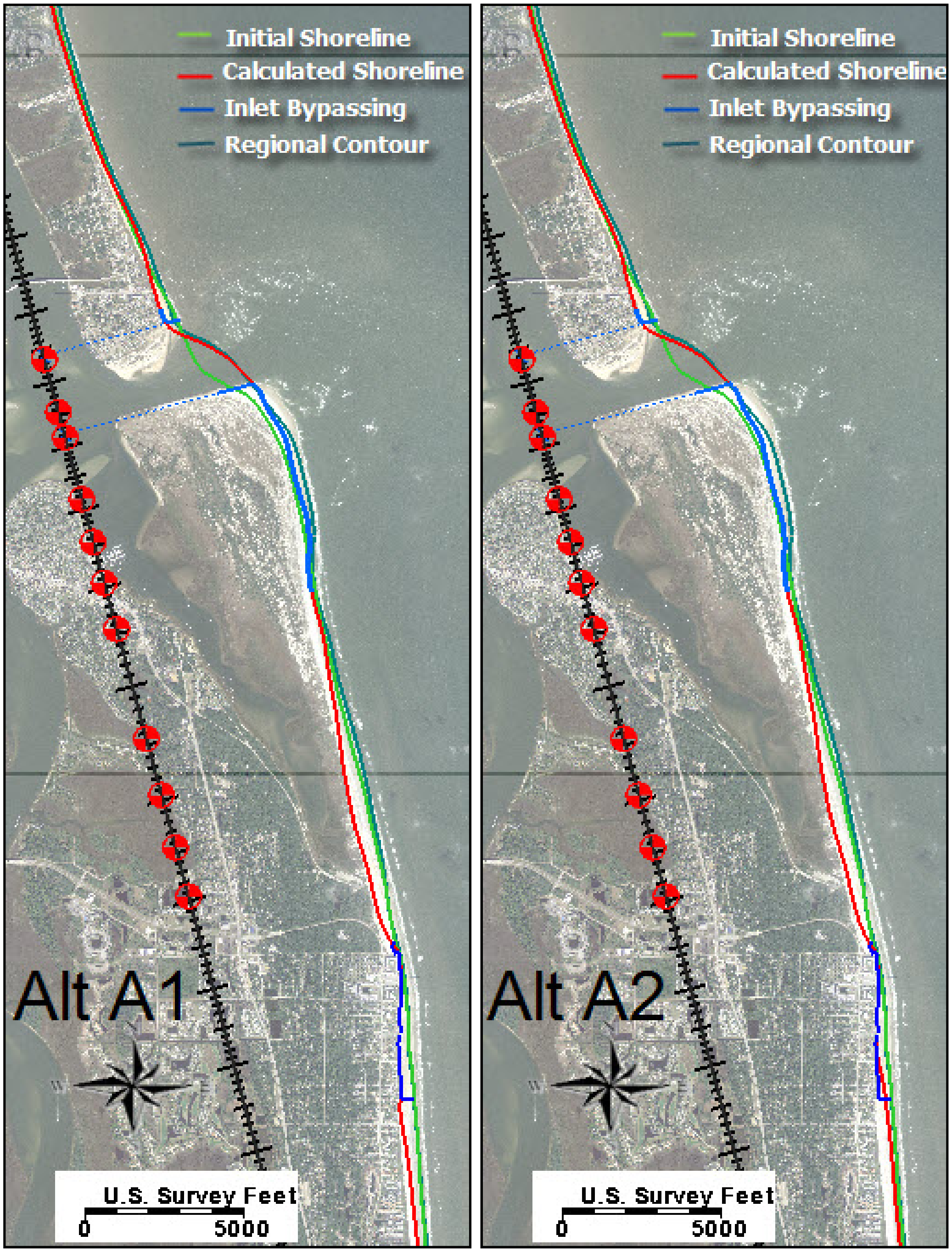

Figure 23. Plots of calculated final shoreline position (red) for Alts A1 (left) and A2 (right).

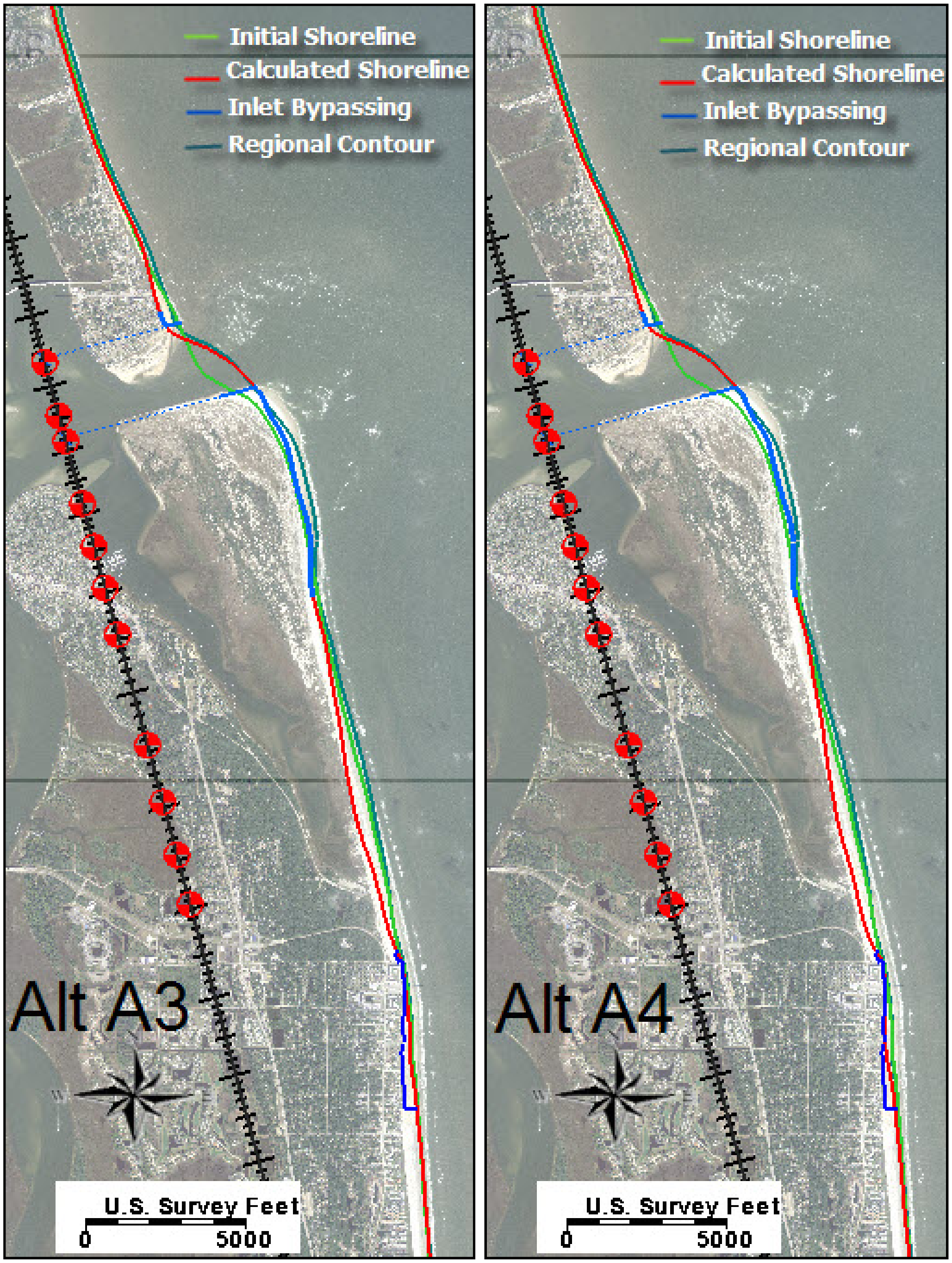

Figure 24. Plots of calculated final shoreline position (red) for Alts A3 (left) and A4 (right).

3.3 Beach nourishment

Dean and Campbell (1999) described a rule of thumb for successful beach nourishment projects consisting of compatible material as having a fill volume of at least 80 cu yd/linear ft for projects in Florida. Ideally, a sediment starved beach is nourished for the first time with a larger volume density such as 100-150 cu yd/linear foot. Following initial nourishment,

beach fills are often most successful with beach fill density templates of 50-100 cu yd/linear foot.

St. Augustine Beach has been nourished in the past (1980s to 1990s) with smaller volumes that had volume densities ranging from 13 to 37 cu yd/linear foot. Beach nourishment in the recent decade supplied approximately seven million cu yd of sediment to a severely starved, 20,000-ft long beach, and broken in to two placement intervals had volume densities of 180 and 280 cu yd/linear foot. This is a considerable amount of volume even in light of the higher wave energy of the 2004 hurricane season. The Jacksonville District intends to renourish with less fill volume at these locations in the future, with a goal of reaching the 80 cu yd/linear foot volume density rule for both shore protection projects.

Although the District is investigating alternative sediment resources for managing the region, this study was focused on the available sediment from St. Augustine Inlet Alternative A1. Two variations of two alternatives were considered in how sand was placed along the adjacent beaches. These alternatives are listed below (Table 12) and reflect the optimal ranges determined both historically and from Alternatives A1-A4.

Table 12. Optimized beach fill placement scenarios following the results of the Alternative 1 dredging scenarios.

Scenario	Dredged Volume	Dredging Interval	Beach Placement Volume		Beach Placement Location & Length
Alt B1	1.35 Million cu yd	5 Years	1.35 Million cu yd	70 cu yd/linear foot	T132 – R151 (20,000 linear feet)
Alt B2	1.65 Million cu yd (Includes Vilano Shoal ~300,000 cu yd)	5 Years	1.65 Million cu yd	40 cu yd/linear foot	R109 – R120 (11,000 linear feet)
				80 cu yd/linear foot	T137a – R151 (15,000 linear feet)
Alt C1	3.0 Million cu yd	10 Years	3.0 Million cu yd	50 cu yd/linear foot	R109 – R120 (11,000 linear feet)
				125 cu yd/linear foot	T132 – R151 (20,000 linear feet)
Alt C2	3.0 Million cu yd	10 Years	3.0 Million cu yd	100 cu yd/linear foot	R109 – R120 (11,000 linear feet)
				125 cu yd/linear foot	T137a – R151 (15,000 linear feet)

1. Alternative B1 represents the base level, beach nourishment alternative that covers the full St. Augustine Beach SPP placement length of 20,000

linear feet as recently conducted in the last decade. This scenario does not include the new work at Vilano Beach, and maximizes the length of placement for the 1.35 million cu yd, 5-year interval.

2. Alternative B2 represents the B1 alternative plus supplementary material of 300,000 cu yd from Vilano Shoal, the inner spit growth along the southern terminus of Vilano Beach, that is placed directly on the Vilano Beach SPP. Because the sand is all of good local "beach quality", extra sand can be utilized from the ebb-tidal delta to increase the volume density at Vilano Beach SPP from 27 cu yd/linear foot (from the 300,000 cu yd alone) to 40 cu yd/linear foot. Placement length for St. Augustine Beach SPP is set to the 15,000 linear feet nourishment template to maximize placement volume per linear foot.
3. Alternative C1 applies the maximum volume that can be removed for the 10-year interval of 3.0 million cu yd. In this scenario, a volume density of 50 cu yd/linear foot is placed over Vilano Beach SPP, with a resulting 125 cu yd/linear foot placed over the maximum reach of St. Augustine Beach SPP.
4. Alternative C2 also applies 3.0 million cu yd over 10 years for both shore protection projects. In this scenario, a volume density of 100 cu yd/linear foot is placed over Vilano Beach SPP, with a resulting 125 cu yd/linear foot placed over the 15,000 ft reach for the St. Augustine Beach SPP.

The final ebb-tidal delta volume and percent difference is given in Table 13. Only Alternatives B1 and B2 lost volume over the 50-year simulation, both less than five percent. A comparison of performance of the ebb-delta recovery of these alternatives is shown in Figure 25. Overall, the 10-year dredging interval appears to allow inlet shoal volume recovery and an increase in total volume.

Table 13. Final ebb-tidal delta volume of each 50-year simulation and the percent difference.

Scenario	Final Volume (cu yd)	% Difference
Alt B1	30,254,520	-2.12%
Alt B2	29,630,114	-4.14%
Alt C1	32,680,608	5.73%
Alt C2	32,680,608	5.73%

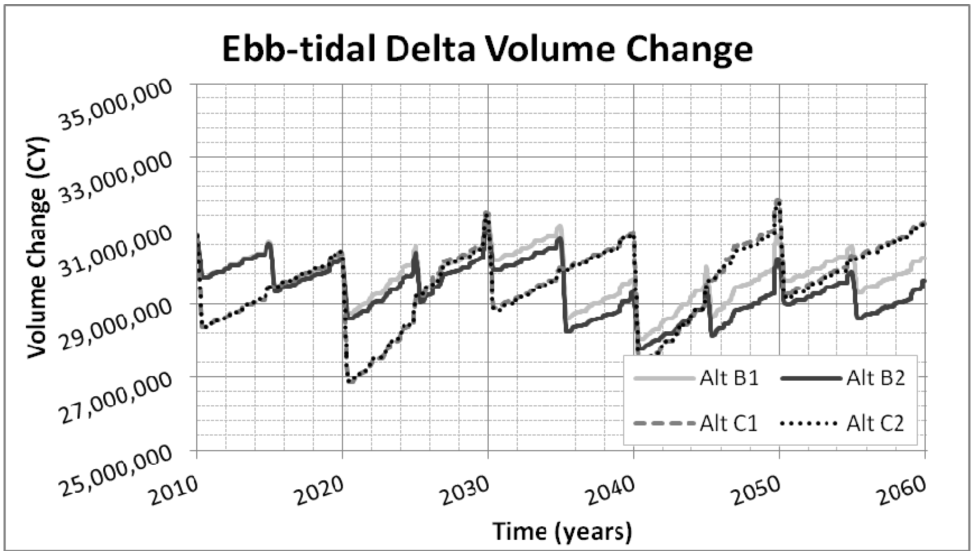

Figure 25. Time-series plot of ebb-tidal delta volume for Alts B1, B2, C1, and C2.

The performance of volume changes and their relative percent difference from total profile volume for the three reaches is shown in Table 14. Alternative B1 does not include a Vilano Beach placement, and loses approximately one million cu yd over the 50 years. However, for St. Augustine Beach SPP Alt B1 and B2 have moderate volume loss at approximately -30 percent, and the additional 300,000 cu yd to Vilano Beach reduces volume loss at the proposed SPP area. Alternatives C1 and C2 had a net volume gain for Vilano beach and Anastasia State Park. Alternative C1 calculated the least volume lost to the St. Augustine Beach SPP, and even retained more volume within Anastasia State Park that was likely acquired from the extensive St. Augustine Beach fills. The very high volume retention within Anastasia State Park is considered a potential positive sand source to the inlet that could not otherwise be bypassed into the inlet due to a lack of inlet processes represented in the model. Overall, Alternative C1 resulted in

Table 14. Final beach profile volume change (cu yd) of each 50-year simulation and the relative percent difference from the total profile volume (from R-Monument to -20 ft MLW) which has an arbitrary elevation per profile.

Shoreline Reach	B1		B2		C1		C2	
	CU YD	%	CU YD	%	CU YD	%	CU YD	%
Vilano Beach	-1,028,289	-11.2%	-395,760	-4.3%	11,403	0.1%	1,084,536	11.8%
Anastasia State Park	894,035	6.2%	622,731	4.3%	1,025,426	7.1%	697,204	4.8%
St. Augustine Beach	-4,357,511	-31.0%	-5,257,507	-37.4%	-5,230,944	-37.2%	-6,542,274	-46.5%

the best performance of all of the projects, including the ebb-delta mining, and resulted in an optimal inlet and beach management plan for St. Johns County.

Figures 26 and 27 illustrate the results of the Alternatives B1, B2, C1 and C2 plotted over the grid domain. Although these alternatives are similar in that shoreline position is relatively the same, several key results can be found in the visualized GenCade results. The shoreline along the seawall portion of St. Augustine Beach was extended beyond the seawall as opposed to being located at the seawall in the A Alternatives. Alternative B1 had the most negative impact on volume change for Vilano Beach, as indicated in Table 14.

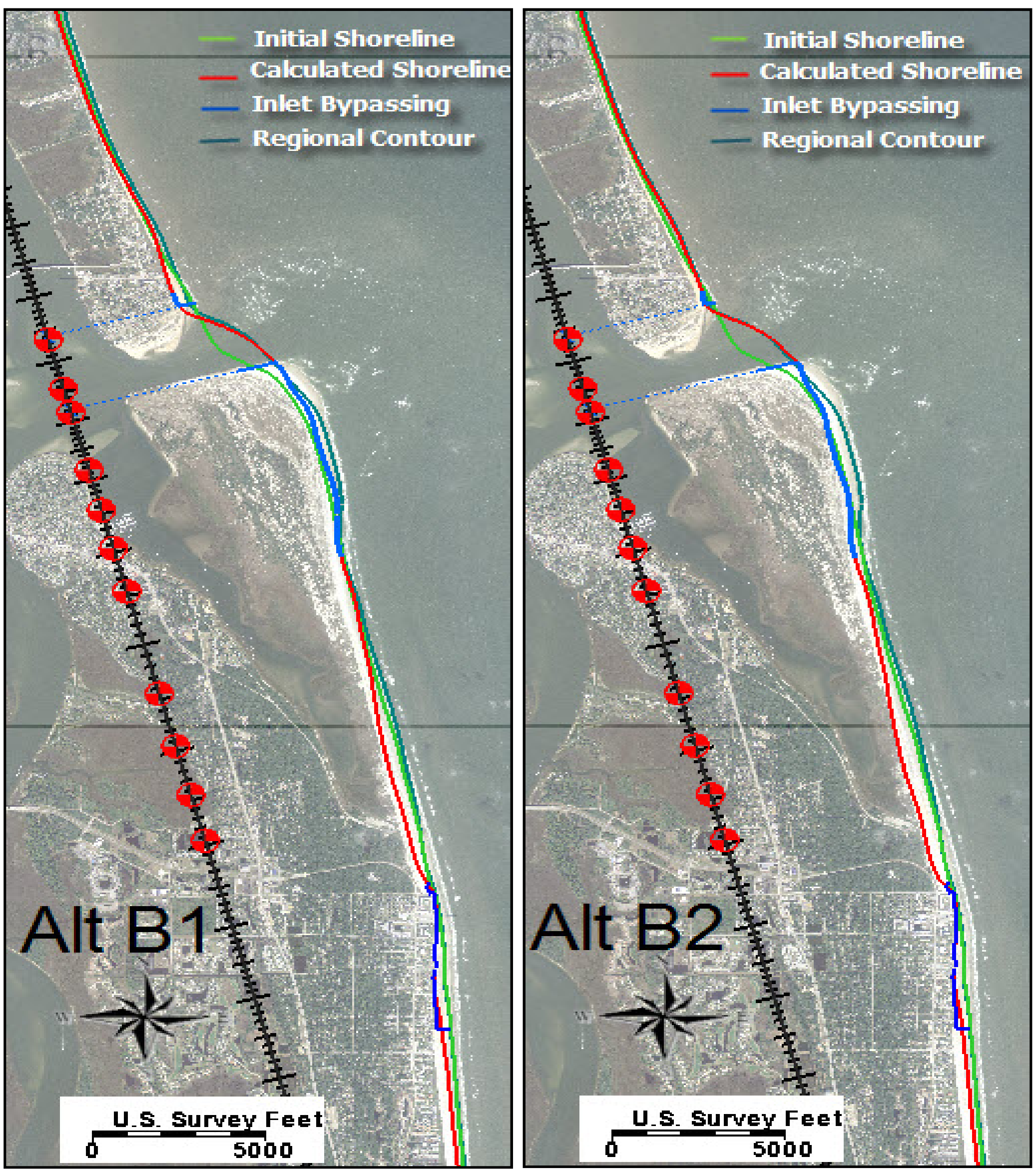

Figure 26. Plots of calculated final shoreline position (red) for Alts B1 (left) and B2 (right).

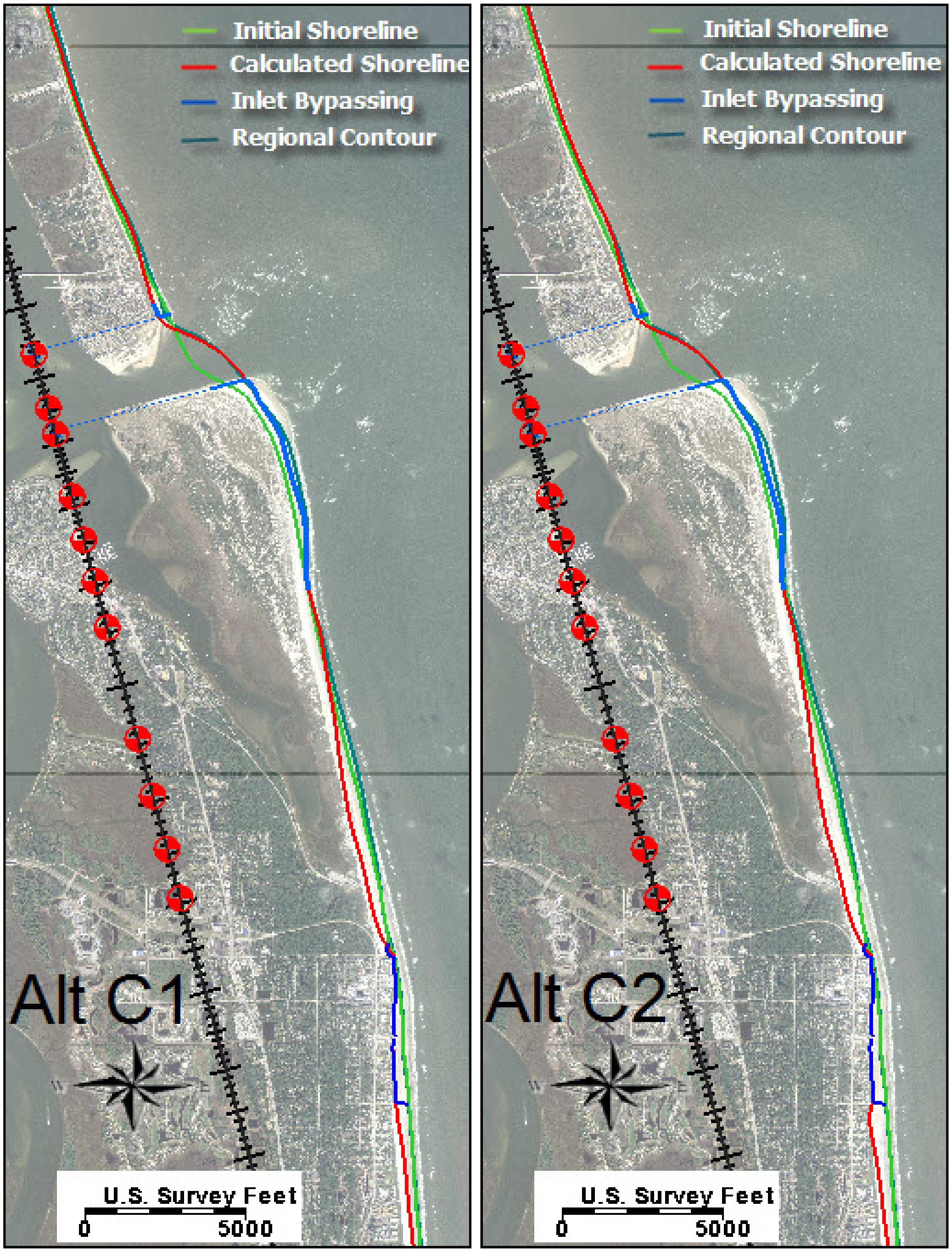

Figure 27. Plots of calculated final shoreline position (red) for Alts C1 (left) and C2 (right).

4 Discussion

4.1 GenCade calibration

The model must be calibrated and validated to separate time periods to determine how well it compares to the real world for the intended use. Ideally, a validation study for a separate time period would be conducted, but was not possible at this location due to the limited availability of data. GenCade was applied here as a planning tool for sediment management optimization for a region that utilizes its primary inlet as a renewable source of sand. The fundamental strength of GenCade is its good description of the relevant processes to calculate how sediment sources and sinks evolve over time. In this application, GenCade improves upon predicted sediment budgets through process-based calculation of coastal evolution. All other physical forcing was characterized in the model with parameters that are interdependent in some manner.

One of the parameters used to simplify the complicated morphodynamics of the region was the jetty bypassing coefficient for St. Augustine Inlet. Aside from the modified wave angles included to account for the sediment transport reversal, the left and right bypassing coefficients, JBCL and JBCR had the greatest influence on the morphodynamics of the shoreline in the vicinity of the inlet and the infilling capacity of the Inlet Reservoir Model. These values are also very much interconnected and modifications to enhance one region will inevitably change another. As stated in the Calibration Section, designation of the JBCL and JBCR coefficients is sensitive to the present morphologic shape of the ebb-tidal delta, the bypassing pattern, and general morphodynamics of the inlet for the given time period. As a result, these values were changed for the 50-year alternatives, and the volumetric change at the adjacent beaches that receive bypassed material are discussed in the following section as directly connected to the inlet shoals.

Although many of the calibrated parameters were modified as appropriate for a standard Genesis/GenCade procedure, the lack of representation of processes that drive the background erosion rate had to be accounted for in the model as a negative sink applied across the entire domain. Figures 10 and 11 demonstrated the need to represent the background erosion rate as documented in Taylor Engineering Inc. (1994). Some hypotheses to explain

why longshore sediment transport could not account for this long-term sand loss are, 1) GenCade is missing cross-shore processes that would transport either offshore or onshore beyond the GenCade domain (from berm to depth of closure), 2) St. Johns County has varying grain size as a function of distance alongshore and therefore equilibrium beach profiles could not be accurately represented as a uniform equilibrium profile across the entire model domain within GenCade, and 3) fine-scale variations in wave direction and energy were not captured in the simplified wave model within GenCade and therefore the necessary wave energy gradients to drive longshore sediment transport were not present in the model. Table 15 lists the measured and calculated volumes of the various beaches and the inlet reservoir volume.

Table 15. Measured and calculated volume change for St. Johns County beaches and inlet.

Location	Reach (R-Mon)	Measured 1986-1999 Volume Change	Calculated 1986-1999 Volume Change	Relative Error
Ponte Vedra Beach	R1 – R109	-7,047,494	-5,570,854	21.0%
S. Ponte Vedra & Vilano Beach	R109 – R122	-993,920	-1,750,050	-76.1%
St. Augustine Inlet	Ebb & Flood Tidal Deltas	5,071,250	3,719,711	-36%
Anastasia Island Headland	R123 – R128	816,874	1,928,059	136.0%
St. Augustine Beach	R128 – R151	-3,296,013	-3,526,604	-7.0%
Crescent Beach to Matanzas Inlet	R151 – R195	-2,338,478	-2,986,960	-27.7%

The calculated results matched the trends of volume change and shoreline fluctuation shown in the measurements during the calibration period. Table 4 listed a one on one comparison of profile volume change over R-Monument reaches (~1000 ft) and found a NRMSE of 6.8 percent and a Correlation Coefficient of 0.61. Calculated and measured volume change for the greater areas was found to have an NRMSE of 10.5 percent, the result of compounded error in summed volume change and different normalization values. Features such as the ebb delta infilling and volumetric growth were captured as a result of the parameterized sediment exchange in the inlet reservoir model. These volumetric accounts of the calibrated results provide an estimate of potential error in modeled long-term scenarios.

4.2 Determining the trajectory of a sediment budget using GenCade

GenCade was applied to evaluate sediment management alternatives that included known historical limits of dredging and beach fill quantities and intervals. Because an extensive analysis of measured data was performed prior to modeling, GenCade was well informed on the realistic bounds of a three-dimensional morphologic environment. This provided confidence in accurately projecting the regional sediment budget for several dredging and beach placement alternatives.

As a planning tool, the GenCade simulations will allow decision makers to evaluate the trajectory of the sediment sources and sinks over time, and to reevaluate, or optimize, with newly informed forcing and data. As an example, results of all beach fill volume and interval alternatives for the St. Augustine Beach SPP were found to have a negative volume adjustment over the 50-year simulation. Maintaining the shoreline location and profile volume of 2010 with the St. Augustine ebb-tidal delta source alone likely cannot be done based on the results of the various alternatives. Because this beach is an erosional hotspot and contains a seawall, once the shoreline recedes to the seawall position, erosion will begin to accelerate due to the influence of the structure. Under the 5-, 7-, and 10-year alternatives examined, this scenario persists and may only be remedied through increased beach fill volume and placement intervals. Ideally, managers would consider other sand resources to mitigate excessive erosion.

The Vilano Beach SPP, however, was calculated to maintain and even grow with ~50 cu yd/linear-foot beach fill volumes at 10-year intervals. Vilano Shoal is a vital source for this SPP, however, lengthening the Vilano Shoal dredging interval and coordinating it with the ebb-tidal delta mining for the St. Augustine Beach SPP will provide more than enough sand to maintain this stretch of beach. Anastasia State Park was also included in the volume change analysis to emphasize its significance and connectivity to bypassing at St. Augustine Inlet. Due to the limitations on represented inlet processes in the model, the calculated volume growth at this beach represents sediment volumes that would otherwise make it to the inlet shoals. This process cannot be fully captured without a process-based morphology model, but inferences on what the volume represents can still be made based on observations in previous studies.

The increase in volume at Anastasia State Park is an illustration of how GenCade results are examined as discrete sediment fluxes that make up a

complete budget. Though not all three-dimensional morphologic processes are represented in the model, most general inferences about sediment transport and bypassing within the coastal zone can be applied to a predicted sediment budget. The benefits of coordinating and modifying dredging intervals can be explored simultaneously with varying beach fill volumes and intervals. This optimization process within GenCade provides a benefit to managers over analytical budgeting periods because real world forcing including storms and various dredging projects can be applied to the projected calculations. However, the most obvious benefit lies in determining optimal mobilization periods and coordinating regional efforts to save in mobilization and demobilization costs for dredging and beach fill placement.

4.3 Role of projects on the future sediment budget

The long-term effects of a single beach nourishment event cannot be superimposed over long time periods on a regional scale using traditional calculation methods of extrapolation when the period of measurement is shorter than the predictive period. This is in part due to the non-linear relationship between length and time scales for nourishment longevity, feedback processes between ebb shoal morphology, and adjacent shoreline change due to unknown longer-term geologic processes. Whereas many desktop sediment budget studies are concerned with the conservation of mass of sediment sources and sinks into the system, GenCade calculates the volume and shoreline change of the regional coastal system with variable forcing, and allows for the evaluation of multiple beach placements at multi-decadal timescales. As demonstrated in this study, GenCade combines the simplified dynamics of the tidal inlet with the adjacent shoreline and the collective effects from single or multiple projects as assessed over a 50-year timeframe. The testing of alternatives, including renourishment intervals, can be based upon realistic dynamic forcing conditions as opposed to the traditional method of relying upon statistical descriptors calculated from previous beach volume change.

5 Conclusions

The GenCade model addressed sediment management questions with semi-empirical calculations of sediment transport to and from sources and sinks within a regional context for St. Johns County, Florida. The performance of GenCade as a management tool can only be equated to its relative accuracy in the calibration process. The capability of this one-dimensional model to predict realistic future scenarios is limited by the calibration assumptions and resultant parameters. Furthermore, extensive analysis of measured data must be performed to inform the model of the realistic bounds in a three-dimensional morphologic environment.

With the aid of historical analysis, GenCade was successfully applied to estimate appropriate ebb-delta mining volumes and intervals. The results of the 10-year incremental, strategic placement of three million cu yd will potentially save up to $10 million in mobilization costs, and reduce O&M needs for the St. Johns County Federal Projects. This guidance will assist O&M Jacksonville District in reducing dredging and mobilization costs for the next 50-year planning horizon.

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14. ABSTRACT

This report, the third in a series documenting a study of St. Johns County, Florida, describes the application of GenCade to the study area as part of a greater Regional Sediment Management (RSM) study. This study illustrates the use of GenCade, a coastal evolution and sediment transport model, as a tool for optimization in management practices for Operations & Maintenance (O&M). Results of the calibration showed good agreement (NRMSE 6.8 percent, Correlation Coefficient 0.61, and Pattern Correlation 93.9 percent) with the measured sediment budget for the study area. The application of the model to calculate long-term with project sediment budget alternatives proved useful in determining an optimized schedule for sediment management activities. The ideal dredging interval for the navigation channel entrance and ebb-tidal delta mining was determined to be most beneficial at 10-year intervals, with beach fill projects being fulfilled at the most favorable placement location and highest yield volume density. The results of a 10-year incremental, strategic placement of three million cubic yards over a 50-year period will potentially save up to $10 million in mobilization costs and reduce O&M needs for the St. Johns County Federal Projects.

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